



OULUN YLIOPISTO  
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# **Importance of Digital Fabrication and its implementation in Finnish Elementary Schools**

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## Abstract

In the modern world, mankind is surrounded with artificial objects which are extended from small pieces of jewelry to the skyscrapers. These physical objects were separated from digital world, but digital fabrication emerged as unique technology which blurred this gap and made it possible to fabricate physical objects with the help of digital and hardware tools (e.g. 3D printers, CNC machines and laser cutters).

The purpose of the thesis is to identify the dynamic aspects of digital fabrication and its implementation in elementary schools of Oulu. Another reason of this research is to highlight the impediments for implementing digital fabrication in elementary schools in Finland. The research is conducted in two different elementary schools of Oulu. Finland is ranked among the top countries in providing quality education. Most of the schools in urban areas of Finland are equipped with state-of-art facilities. The libraries and laboratories have modern facilities with latest technologies.

The thesis research is carried out by using qualitative research method, which includes data collection by distributing questionnaires to the elementary school children, interviewing teachers and laboratory supervisors and getting feedback from them. Based on the results from questionnaires and feedback from teaching staff and students, the research data has been analyzed. The research results revealed that most of the students possess basic knowledge of 3D printing and digital fabrication but due to lack of its facilities in school laboratories, they are unable to learn and practice. The school teachers and laboratory supervisors with the help of school administration can play a fundamental role in successful implementation of digital fabrication in elementary schools.

### *Keywords*

Digital fabrication, design thinking, 3D printing, Fablabs, elementary school children

### *Supervisors*

Professor Netta Iivari and Professor Marianne Kinnula

## Foreword

The thesis has been written as a part of the master's degree program in Software Systems and Services Development in Global Environment at Department of Information Processing Sciences, University of Oulu, Finland.

The theme of the thesis was conceived by the supervisor and this thesis is the continuation of the work done by the department to get the data regarding design thinking in school children.

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# 1. Introduction

In the recent decade, information technology researchers have been working to bring the humans closer to the digitalized world, where humans can interact with the digital technology to perform their daily chores. Ubiquitous computing is also a step towards bringing the human beings closer to digital technology. There are several forms of the digital technology e.g. computers, mobiles, television etc. These digital technologies played a vital role to make the life easier for human beings. For example, mobile phones were used as a device which can help you to call or text some relative or family members, but nowadays mobile phones are smart and become part of our daily life. We can perform multiple tasks through our smart phone which includes browsing web, connect to social media (e.g. facebook, snapchat and twitter etc.), payment for groceries at supermarket, finding any location, playing 3D games and many more.

Likewise, in the field of information technology, computers and other hardware devices are becoming more advanced to ease the life of mankind. The computers and printers are now used to bring the digital design into physical object. 3D printers are used with the help of 3D designs software to print different type of small and large-scale objects. These objects could be as small as the needle or as large as full fledged house. The process of printing the three-dimensional physical objects through computers is called "Digital Fabrication".

Digital fabrication also known as digital manufacturing, additive manufacturing or 3D printing was first introduced by researchers in Massachusetts Institute of Technology (MIT), where they connected the computer with milling machine and used computer tools to create tangible physical objects by using numerical controlled machine. Now, computing numerical controlled (CNC) machines can produce everything for industrial and non-industrial use. Digital fabrication did not only bring revolution on earth but also in space where NASA scientists are testing designs that will function in zero gravity, on the airless moon and even on the other planets around the universe (Gershenfeld, 2012).

As digital fabrication is revolutionizing every field of life in modern world, researchers felt the need to spread this technology around the globe where people are less resourceful and could not afford to explore this revolutionary technology. Dr. Neil Gershenfeld who is researcher and professor in MIT came up with the concept to introduce fabrication laboratories (FabLabs) in developing countries. To execute his concept, he first launched FabLab in a remote Indian village with the collaboration of other researcher and technical organizations.

To understand the purpose of implementation of digital fabrication laboratories in schools, it is necessary to get some introduction about digital fabrication, 3D printing and its different branches. In this thesis, I have tried to conceive the whole picture of digital fabrication and explain it elaborately so that I would be able to find out the reasons for which junior schools are still lacking this facility. The process of digital fabrication is to transform a digital design into a tangible object. At one time, digital fabrication required expensive manufacturing plants for computer-aided design (CAD) and computer-aided manufacturing (CAM). But today, personal fabrication systems are beginning to allow individuals access to these same technologies (Bull et al., 2009).

Digital fabrication also known as 3D printing, digital prototyping and additive manufacturing is the process to design and print any physical object with the help of open source computer software. This object could be smaller or bigger depends on project



nature. To learn the whole process of digital fabrication, there are almost 1250 FabLabs around the world providing free services to their citizens regardless of their age and experience in technology field. Since this technology is freely used in Fablabs and other commercial areas. Personal fabrication offers the opportunity to democratize innovation. Schools must provide early access to the tools needed to develop skills required to take advantage of this opportunity. The next Bill Gates or Thomas Edison is undoubtedly in one of today's schools, just waiting to get his or her hands on a fabrication system (Bull et al., 2009).

In Finland, modern technology startups e.g. mobile applications, gaming and wireless technology companies are increasing manifolds and Finnish people are adopting novel technologies at home and at work. Schools in Finland are equipped with modern teaching equipment and school laboratories have modern technical tools. Schools encourage students to participate in technological workshops and seminars which help students to learn and challenge their competencies. Since students have started learning programming languages in elementary schools, there is a need to introduce digital fabrication and 3D printing technologies in every school so that students can engage themselves in creative activities. There are various elements involved in the process of digital fabrication, but design thinking is the key factor to influence the school children towards digital fabrication. According to recent statistics, there are very few schools in Finland where they have 3D printing facilities. Researchers in universities are working hard to promote digital fabrication in Finnish schools by organizing workshops and summer school camps in different schools (Blikstein, 2013).

*Research question 1:* Why it is important to implement digital fabrication in Finnish elementary schools?

*Research question 2:* How can digital fabrication and design thinking can revolutionize junior school children learning experience?

## 2. Structure of the thesis

The core theme of this thesis is to highlight the importance of digital fabrication and its importance in elementary school. The thesis starts with the introduction part, which describes the general idea of digital fabrication and the origin of this technology. The tools and technologies which can be utilized to achieve desired artifacts. After introduction part, background of this technology and how it became so popular in universities and corporate sector will be discussed. Following the background and motivation part, a brief detail of digital fabrication technology, tools and other aspects of digital fabrication will be described. Design thinking plays a pivotal role in the process of digital fabrication. To be successful in this modern technological and highly competitive world, students need to learn multi-dimensional skills and one of these skills is design thinking. Design thinking, process of design thinking and its importance in schools is briefly described in this thesis.

Fabrication laboratories also known as FabLabs provides the platform to experiment different tools and accessories e.g. CNC machines, laser cutter, 3D printer etc. Wi-Fi became a basic need of almost every household. FabFi is a technology quite similar to Wi-Fi, which was used first time in Afghanistan to get the basic communication facilities. FabFi is also discussed in this thesis. Maker movement and its importance in education is also highlighted in the thesis. Few years ago, FabLabs were only existed in universities and corporate sectors, but now FabLabs are gaining popularity in junior and high schools. The importance of FabLabs and its significance in school have also been discussed.

In chapter 6, previous literature regarding digital fabrication in schools, design thinking and its processes from different researchers will be discussed. Chapter 7 covers the research methodology, data collection and how data will be analyzed. The results are drawn based on the qualitative research and will be discussed.

In the end, conclusion with advantages and disadvantages of the qualitative survey will also be highlighted. As an end note, some suggestions are given for future research.

### 3. Background and motivation

The popularity of 3D printing and digital fabrication fascinated me to write my thesis about digital fabrication and its implementation in schools. Usually, modern and advanced technologies are only available in universities or offices, but secondary and elementary schools are provided basic technology in laboratories. 3D printing became famous in early 2000's and now commercial and non-commercial firms are widely using this technology to design prototypes for their customer's satisfaction. Initially, 3D printing technology was only used for architecture design purposes but later with the advancement in 3D printing technology, new tools and techniques were introduced and universities started to adopt this technology and designed FabLabs for students. There are number of journals and articles available regarding use of digital fabrication and its implementation in commercial sector but very few articles can be found for the implementation of this technology in schools.

To promote excellence in education and skill development is one of the key elements within the "Innovation Union" Flagship Initiative (2012) under Europe 2020 strategy. The "Innovation Union" communication recognizes that weaknesses remain with science teaching; the skills for future responsible innovators/researchers as well as for "scienceactive" citizens have to be built starting from early age including scientific reasoning, as well as transversal competences such as critical thinking, problem solving, creativity, teamwork and communication skills.

Every decade of this century brought different level of skills and intellectual activities, which were vital for work and for social responsibility. Some of those skills were only accessible to experts in previous decades. When we look at 70's century, computer programming emerged as a new sensation, but the computers were so expensive and large, so it was only accessible to professionals or in universities. The hard work and dedication of researchers brought this dream into reality. Personal computers, smartphones and modern gadgets are all results of those innovations achieved during last few decades. 3D printing also known as digital fabrication or additive manufacturing is also a part of those modern innovations. (Papert, 1991; Alimisis, 2013.)

Neil Gershenfeld is among the pioneers for introducing 3D printing in universities and school. 3D printers are very popular topic nowadays due to low-cost 3D printers available in the market. There are striking parallels between the advent of 3D printer and that of the personal computer. One parallel that is worth noting is interest that is sparked by these technologies in children. "Digital fabrication and "making" could be a new and major chapter in this process of bringing powerful ideas, literacies, and expressive tools to children. Today, the range of accepted disciplinary knowledge has expanded to include not only programming, but also engineering and design." (Blikstein, 2013, p. 2.)

We are living in a world increasingly shaped by technological procedures and digital devices. In order to actively participate in such a world, we increasingly need to be able to both understand and to use these technologies confidently and competently. The advent of Fabrication Laboratories opens up the possibilities for engaging in the production of these technologies directly, making the equipment and materials for such digital fabrication available beyond the borders of a few highly specialized companies and research institutions and putting them into the hands of the general public. In doing so, it is hoped that a widespread, diverse and personally relevant creation and use of technology can be fostered. (Gershenfeld, 2005; FabLab FAQ, 2012.)



The technology investment in schools worldwide has increased more than a hundredfold in the last two decades. Much of this investment has been made based on the assumption that technology-mediated learning environments provide opportunities for students to search for and analyze information, solve problems, communicate and collaborate, hence equipping them with a set of competencies to be competitive in the 21st century marketplace. However, the history of the use of technology in schools has suggested that educators would abandon technology that does not fit the social organization of schooling. (Cuban, 2005; Lim, 2007; Zhao & Frank, 2003.)

Children now grow up immersed in technology to a level that keeps surprising earlier generations, but which, to them, is simply an inherent element of their habitat. Although this involvement is largely dependent on wealth and circumstance, it is certainly the case that children are frequently users and increasingly owners of personal computers, game consoles, personal music technologies and mobile phones. More than ever before, technology manufacturers and service providers are turning their attention to children as a growing market segment. Even more important, societies are becoming concerned to ensure that appropriate products and services, namely those that can support development and enhance well-being, are being made available for children. Whatever motivates the design of interactive technology for children, it is clear that there is an urgent and present need for research in the design of interactive products for children, related methodology, as well as a scientific account of the interaction between children and technology. (Dutta et al., 2011; Read & Markopoulos, 2013.)

The research found that “Digital fabrication had the potential to be the ultimate construction kit, a disruptive place in schools where students could safely make, build, and share their creations. I designed those spaces to be inviting and gender-neutral, in order to attract both the high-end engineering types, but also students who just wanted to try a project with technology or enhance something that they were already doing with digital fabrication” (Blikstein, 2013, p. 6.)

We surround ourselves with artificial objects that range in scale from tiny pieces of jewelry to the huge buildings where we live and work. Historically, the separation of the physical and digital worlds has been very clear, but digital fabrication is blurring that dividing line. So far, digital printing technology can only generate relatively simple objects. However, artifacts in our modern world can in many cases be seen as an instantiation of a plan, which can be data or software, and fabricating programmable devices that have complex physical characteristics and functional parts is the next logical step in the technology evolution (Schmidt et al., 2011).

## 4. Digital fabrication

Digital Fabrication is a process of translating the digitally prepared design into a tangible entity. Neil Gershenfeld promoted the concept of personal fabrication through fabrication laboratories in MIT's department "Center for Bits and Atoms" (CBA). 3D printing also known as additive manufacturing and rapid prototyping is a synonym of digital fabrication. Digital Fabrication can also be described as a process where different machines are numerically controlled by the computer to make useful physical artifacts (objects). These objects could be used not only for industrial purpose but also for medical and household items. These objects are initially designed digitally in the computer by open source software and then processed through different machines. These machines are commonly known as e.g., CNC machines, laser cutters and 3D printers. There is a wide of range of 3D printers and different digital fabrication related machines are now available in the market (Gershenfeld, 2012).

In digital fabrication the ability to work with digital materials, which can be programmed according to parameters of design, function, ornament, efficiency, etc., is understood. What is now called "digital fabrication" is not quite there yet: digital information is used to operate computer-controlled machines, which can run codes specifying coordinates and instructions like subtract, add or deform materials in different physical states. The road to total digital fabrication passes through the possibility of programming matter at scales which are not visible to the human eye – for example, within the human body and in nature within living organisms – so as tap into the search for energy efficiency, survival or evolution, to mention only some of the characteristics, which motivate them (Diez, 2012).

### 4.1 Digital fabrication for industrial use

Digital fabrication revolutionized the industrial infrastructure. The revolution is not additive or subtractive manufacturing, but it is ability to turn digital data into things and things into data. Now this technology can be applied in almost every field of science. In the civil engineering department, digital fabrication helps the engineer to build a prototype model through 3D printers to check the sustainability of the buildings. In the mechanical engineering department, engineers are making different mechanical parts through 3D printers, which are not only reliable but also comparatively cheaper. In the medical sciences field, doctors are using 3D printed prosthetic body parts, which can save the humanity and also reduce the cost. Low cost, versatility and user-friendly process make digital fabrication technology accessible to K-12 teachers and students. In the space sciences, NASA researchers are testing designs that will function in zero gravity, on the airless moon and even supports the human exploration on other planets like Mars. Defense industry is using digitally fabricated military equipment parts for on spot repair for the troops who are deployed far from their country. For example, US Navy ships operate in the deep sea for extended period of time, they use the digital fabrication technology for on-board repair and modification in the military equipment. (Gershenfeld, 2012; Espalin et al., 2014.)

*How does it work?* The process of digital fabrication is a lot simpler than other industrial processes. First, we need to have idea about the final object. After conceiving the idea, the prototype will be designed in any open source software available in the market. To print the prototype, it is recommended selecting the nature of final product. Most of the



labs use laser cutters or CNC machines instead of 3D printers because machines work faster than 3D printers (Blikstein, 2013).

Digital fabrication tools turn bytes into atoms, i.e. they create material objects from digital designs. A computer-aided design (CAD) model is fed into a fabricator which then builds its physical instance from a stock material. Laser cutters, computer numeric controlled (CNC) routers/mills, and 3D printers are amongst the most practical and versatile of these tools. While laser cutters and CNC routers/mills create parts by cutting away at sheets of wood, acrylic, metal, cardboard and other flat stock, 3D printers build the objects up by depositing and binding successive layers of materials such as thermoplastics, ceramics and powdered metals (Mota, 2011).

## 4.2 Community-based digital fabrication

Hielscher & Smith discussed the idea of community-based digital fabrication workshops (such as Hackerspaces, FabLabs and Makerspaces). These workshops are innovative spaces where people come together to learn and use versatile digital design and manufacturing technologies and create things in collaborative projects. Some spaces are run voluntarily, while others receive institutional support (e.g. from universities and libraries), but all share philosophy towards providing workshops that can be freely accessed by the wider public. The participants in the workshops are involved in variety of practices in these spaces, and that go beyond tinkering with technologies and making things, to include experiments in principles ideas for common-based peer products that some observers claim might be relevant for a post-consumption society. (Hielscher & Smith, 2014.)

The authors also highlighted the statement of Lassiter (2013) regarding hype of grassroots digital fabrication technologies and their potential social consequences. According to Lassiter (2013, p. 252.), "The cost and complexity of digital fabrication technologies are coming down very quickly, bring the tools and capabilities for invention and innovation within the reach of almost anyone, almost anywhere in the world. That kind of democratic, distributed capacity is revolutionary. It promised to change everything... the way we design, manufacture, finance, communicate and market for business, supply chains, the platforms upon which we build businesses, the way we educate and conduct research" (Hielscher & Smith, 2014.)

## 4.3 Additive manufacturing

A rapid and productive transformation happened throughout this century which helped mankind to improve their living standards. The role of technologies in everyday life has been increased over the past few decades. In the digitalized future, where humans need more digital products, there will be a need to replace products and even human body parts with minimal waste. Back in days, when first computer was invented it was quite big that it occupied the whole room and the memory of that computer was in 1-2 mega bites, but the evolution of computers made it so compact that now it can be carried in a small backpack. As the old technologies became obsolete and new technologies replaced them, similarly in the digital media where printers were used to print out documents or pictures, now 3D printers can be used to produce 3D object designed and developed into the computers. The novel modern technologies make it possible for humans to interact with the digital technologies (Wong et al., 2012).

#### 4.4 Design thinking and its implementation in schools

**Design thinking** is generally defined as an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign. Design thinking can also be explained that it is a methodology used by the designers to solve complex problems and find desirable solution. Design thinking is an approach to integrate the social needs, the possibilities of technology and the requirement of business success. To become successful in this competitive world, one must acquire different kinds of skills and possess innovativeness in his field as compare to the past. Design thinking is one of those skills, which distinguish a successful person over common people. Usually, design thinking related as a part of engineering, architecture and technological fields but now it is not only important in technological field also business firms are promoting design thinking (Razzouk & Shute, 2012).

In many fields, knowledge is generated and accumulated through action (i.e., doing something and evaluating the results). That is, knowledge is used to produce work, and work is evaluated to produce knowledge. Creative people tend to work in two different ways: either as finders or as makers. Finders execute their creativity through discovery whereas makers are equally creative, but they synthesize what they know about new patterns and designs. To understand the fundamentals of design thinking, we first should know the design process. The researchers proposed different types of framework and processes for design thinking, but the creativity and intuition are the pillars of design thinking (Owen, 2007).

The design process is characterized by being iterative, exploratory and sometimes chaotic. During the design process, designers deal with several different cognitive processes. Kolonder & Wills specified three processes required in design thinking: (a) preparation, (b) assimilation (adaptation) and (c) strategic control. In the early stage of design thinking process, designers focus on relevant inventions and inspirations which modifies depending on the specification and visualization of the project. The adaptation (assimilation) process involves generating ideas and making mind maps of the proposed solution, data and observation coming from the design environment, such as feedback from experiments and survey. In the strategic control or implementation phase, designers must decide which idea or prototype will suit the project requirement. This expertise concludes in a rare innovation and unique designs. Expertise is the result of dedicated application of specific field of interest. (Braha et al., 2003; Kolonder & Wills, 1996; Cross, 2004.)

The expertise can be shared between two types of people, experts and novices. The major difference between experts and novices is that experts have accumulated many types of problems and solutions in a specific field of interest. The novice behavior is associated with identifying and exploring the solution of any problem. The novice mostly got trapped gathering information rather than progressing to solution whereas experts do not collect as much information, but they are still able to solve the problem. Therefore, the accumulation of experience is critical in the transformation of a novice to an expert. The students in early education are also novices as they face different kind of challenges in designing and presenting their class project. The students should be aware of the design thinking process to get the confidence for undertaking any action while facing difficult challenges in future endeavors (Razzouk & Shute, 2012).



## 4.5 Technology integration and design thinking in K-12 education

A rapid and productive transformation happened throughout last few decades which helped mankind to improve their living standards. The role of digital technologies is also increasing in everyday life, resulted in changing the society norms. Therefore, it is important to prepare the school children for future challenges. In the 21st century different skills like critical thinking, creativity, communication and digital literacy are gaining popularity in school education. The research has shown that the learning is enhanced using technology and that students need to develop technology skills to meet future challenges. To provide quality education to school children, it is important that teachers use educational technologies effectively in classrooms and teach their students how to use technology for learning purposes. “Early studies suggested that integrating science, technology, engineering and mathematics (STEM) in a highly motivating task that makes use of digital fabrication can facilitate learning, developmental skills, and student engagement.” (Berry et al., 2010, p. 169).

In today’s world when presence of digital technology is emerging as a potential tool, it is important to recognize the significance of technology in our society. For instance, ubiquitous technology not only has the potential to decrease social isolation of elderly people but also vision impaired people can walk through the city center with their smart stick. To understand advanced technologies, children don’t need to learn the hardcore technology skills e.g. programming and electronic circuits, but they should also gain insights how such technology can impact their personal skills. One of the 21st century skills involves digital literacy. We broadly interpret digital literacy as the ability to use, understand and evaluate technology, and to understand technological principles and strategies required to develop solutions and realize specific goals. As a classroom tool, the computer has captured the attention of the education community. The computer can store, manipulate, and retrieve information, and it has the capability not only of encouraging students in instructional activities to increase their learning but also help solving complex problems to enhance their cognitive skills. (NAEP, 2010; Voogt & Roblon, 2010; Boswinkel & Schram, 2011; Johansen & Reeves, 1996.)

There have been numerous developments already facilitated the integration of digital tools in school context to teach children about digital literacy. These include FabLab equipment, such as 3D printers, laser-cutters, CNC machines, but also digital toolkits that support low-threshold “making” of diverse digital solutions for various problems. These digital toolkits which facilitate school children to learn digital fabrication of various application using programming and electronic hardware such as 3D printers and laser-cutters include Lego WeDo and MakeMonkey (Blikstein, 2013).

“Often schools are teaching kids things they might never need to know again. We’re not teaching them how to be creative, or design, or deal with unexpected situations. A lot of people are aware that we really need to change education, but they don’t know how. This is one method that could inspire people. It’s basically design thinking, adapted for children.” (Emer Beamer, Dutch design thinker.)

What teachers do in classrooms is a reflection on their training. Some of the most skillful IT teachers in the school community are doing much less with technology than they could. Teacher education programs are understandably in a transitional phase with regard to IT, which is a still relatively new subject on the university’s curriculum. While there appears to be wide acceptance that teachers should be better prepared to use IT in their classroom instruction, there may be some concern as to how best to affect the proper training. Technology workshops and other special offerings continue to be an important resource

for teachers training. (Schrum, 1999; Strudler & Wetzel, 1999; Willis & Mehlinger, 1996; Bauer & Kenton, 2005.)

The model of design thinking proposed by Hasso-Plattner institute of Design at Stanford (d. school) suggests that the teachers should give their students some challenges to let them understand the design thinking process. They proposed a framework of design thinking, which can be used in random order in different situations (Thoring & Mueller, 2011).

Design thinking would be a great tool for educators to deploy in their classrooms and schools, and it would be a useful process for children working through interdisciplinary challenges. The best part of design thinking is to focus on solution rather than problems. By adopting the solution-based mindset, students would be no longer worried about failing while they are focusing on finding a solution. While design thinking is gaining enormous popularity all over the globe and many teachers/educators are adopting this process to broaden the minds of students, it is also necessary to integrate this process with digital technologies so that students can learn about digital technologies without fear of failing (Baeck & Gremett, 2011).

## 5. Fabrication laboratories (Fablabs)

A FabLab is a technical rapid prototyping platform for innovation, creativity and learning: a place to play with modern digital fabrication tools and to create innovative artefacts through computer-controlled machines and 3D printers. A Fab Lab is a small-scale workshop offering digital fabrication. It is comprised of custom-made fabrication and electronics equipment, which help to transform a digital design into tangible object by using an open source software. The Fab Lab at University of Oulu contains, among other machines a laser cutter that makes 2D and 3D structures, a milling machine to make molds for casting, two 3D printers and several electronic stations (multimeter, oscilloscopes) (Gershenfeld, 2012).

The FabLabs was first conceptualized by MIT's research class with the title "How to make (almost) everything" which later became popular and CBA started working on the project to transform the idea into physical form. FabLab is an educational project initiated with the collaboration of two research groups Grassroots Invention Group and of MIT's Center for Bits and Atoms (CBA) which is an extension of its reach into digital fabrication and computation. Grassroots Invention Groups is no longer affiliated with MIT's media lab but CBA is still actively involved in FabLab activities. FabLabs were established with the aim to spread the modern information technology learning and tools in the far reach and under-served communities in the world (Gershenfeld, 2012).

FabLabs today are equipped with CNC machines such as 3D printers, laser cutters, milling machines, knife cutting machines and sufficient equipment to produce in-circuit boards, which allow the production of electronic projects. This vast set of tools allows the production of new technologies, and of course it is possible to produce the machines of a Fab Lab inside a Fab Lab: it can have "children", a self-reproducing organism (Diez, 2012).

It is important to note that education can take the FabLab users far, but the presence of someone who is familiar with the machines' idiosyncrasies and can serve as a resource for all users is incredibly important. The initial education that a new FabLabs site will receive will not yield immediate gurus, but experts, local and from afar, will be necessary over the lifetime of a FabLabs to field questions and solve quirky machine problems (Mikhak et al., 2018).

### 5.1 Fab Foundation

The Fab foundation was founded in 2009 to extend the network of FabLabs around the world. They are committed to bring technical capacity abilities in communities to develop themselves and their communities and bringing access to tools and knowledge that encourage innovating practices. The aim of Fab Foundation is to provide free access to anyone anywhere to the tools, knowledge and information of technical invention and digital fabrication under one roof. The first FabLab was installed in Vigyan Ashram, India with the collaboration of MIT. With the efforts of Fab foundation, now there are almost 1200 digital fabrication labs over more than 100 countries around the globe. The Fab foundation is also providing guidelines and technical assistance for setting up a new FabLabs (fabfoundation.org, 2017).

"Necessity is mother of Invention", a famous quote can be justified here when residents of Jalalabad, Afghanistan established a Wi-Fi with the help of National Science Foundation (NSF) and MIT's Center of Bits and Atoms. They installed a small scale,



open-source system to transmit wireless ethernet signals across distance of several miles. This low-cost project was started by using USAID vegetable oil cans as reflectors for mounted wireless routers. The residents of the area took one-month training in FabLab academy in Jalalabad and determined to build a Wi-Fi which could be useful for hospitals and schools in the surrounding areas. They gathered metals, wires, plastic tubs and some wooden boards out of trash to build FabFi node. Now that FabFi covering most of Jalalabad area consists of 45 nodes transmitting a wireless signal as far as 3.7 miles with connection speed of 11.5 Mbps. After the successful launch of FabFi in Afghanistan, Kenya has also followed the same path and launched 50 remote FabFi nodes across three sites with the maximum covering area of 3.5 kilometers. The data can be transferred with the speed of 30 Mbps with this FabFi facility (fabacademy.org, 2009).

## 5.2 Maker movement

The Maker Movement refers to the growing number of people who are involved in the production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others. Dale Dougherty launched Maker Magazine in 2005 with the intention to bring those communities closer who are engage with some skillful hobbies not related to household chores but some hobbies where they can make difference and create something unique and useful for their communities. Later, Maker Faire was established in 2006 at Bay Area, USA with the idea to expand the community learning and created a space where magazine readers could get together to extend their conversation. In that gathering, a maker could put up an object they created on the table and the other participants started asking about it. (Halverson et al., 2014; Dougherty, 2012.)

The Maker Movement was founded as a part of that get together because people needed to engage passionately with objects in ways that make them more than just consumers. Makers as their core were enthusiasts, such as those who were engaged with computer industry in Silicon Valley. Although the movement is largely driven by the internet, events like Maker Faire allow people to mix with many different groups. Maker Faire brought together makers of things who rarely associated in our everyday world. They seem to belong together, connected by enthusiasm and a common passion. Making refers to a set of activities that can be designed with a variety of learning goals in mind. Making can happen in a variety of places that may be labeled “makerspaces” as well as in classrooms, museums, libraries, studios, homes, or garages. (Dougherty, 2012; Halverson et al., 2014.)

Maker movement can be described as a community of hobbyists who develop different projects for both playful and useful ends. There is growing interest among educators in bringing making into K-12 education to enhance opportunities to engage in the practices of engineering, specifically, and STEM more broadly. He highlighted three elements of the Maker Movement, and associated research needs, necessary to understand its promise for education: 1) digital tools, including rapid prototyping tools and low-cost microcontroller platforms, that characterize many making projects; 2) community infrastructure, including online resources and in-person spaces and events; and 3) the maker mindset, aesthetic principles, and habits of mind that are commonplace within the community. It further outlines how the practices of making align with research on beneficial learning environments (Marin, 2015).



### 5.3 Maker movement in education

A century ago, John Dewey praised the benefits of learning by doing and researchers confirmed the importance of tactical engagement of using our hands in the learning process. The school juniors nowadays lack motivation in school and as a result, they consider themselves as poor learners. We should be framing things in our schools not just in terms of “how do we test on that?” but on “what can you do with what you know?” When you are making something, the object you create is a demonstration of what you have learned to do, so you are providing evidence of your learning. Dale Dougherty suggested finding teachers who are themselves makers. They understand the relevance and importance of making things, also can act on it and connect with their students as mentors. Dale Dougherty’s vision for the educators was to bring the under-served students into mainstream so they can become valuable citizen for their communities in near future (Dougherty, 2012).

How educators can design classrooms as makerspaces by focusing on student interest and by understanding learning as integrated and connected through projects rather than as an isolated set of skills. And while school-based makerspaces will likely include the newest technological toys, such as 3D printers and laser cutters, the focus in design for learning is not on tools but on the process and the product. FabLab is the continuation of that effort to let the juniors and sophomores create something unique and useful by designing different artifacts using computers and computer-controlled machines and 3D printers. Professor Neil Gershenfeld created FabLabs to provide a platform where people regardless of their age, ethnicity and race can participate and solve their problems by creating some artifacts they need (West-Puckett, 2014).

### 5.4 Fablabs in schools

To promote design thinking and iteration process is becoming popular in schools. The children in primary and high schools are eager to learn new technologies and they have better access to modern technologies than the school children of 80’s and 90’s. It depends on the teachers and educators to develop the children’s learning process by providing them new technologies. In most of the primary schools, junior students are learning how to develop a simple computer application. As students are learning programming and coding, they should also have the opportunity for developing and articulating physical objects by learning digital fabrication in FabLabs. It will not only increase their design thinking but also improve their attitude towards making physical objects by their own effort and dedication (Blikstein, 2013).

One of the 21st century skills involve digital literacy. We broadly interpret digital literacy as the ability to use, understand and evaluate technology, and also to understand technological principles and strategies required to develop solutions and realize specific goals. This includes providing children with an understanding of the use of various digital technologies, including social media, digital fabrication techniques, sensors, actuators and computing technologies. The educators in most of the developed countries are finding new and modern ways of teaching their students, so the students can take their studies seriously and learn modern technologies. Most of the today’s children where they are familiar with latest devices e.g. mobile phones, tables, laptops and printers, they are also aware of popular mobile apps, games and software. They spend more time on mobile and tablets than ever before. As the junior students are consuming precious moments of their life in useless hobbies, it is the job of educators to engage them in learning new useful technologies and FabLabs are the perfect places for them to think and create useful artifacts by their own hands (Bekker et al., 2015).

FabLab can be a place of great interest for children in terms of learning and learning by engaging with emerging technologies. Ideas about projects they want to do next and reflections on the realized projects also indicate that they are able to transfer learned skills and experiences. An especially crucial factor for the children's sense of satisfaction appeared to be the technical challenge and mastery of the task and the personal engagement associated with the result (Posch, 2012).

### 5.5. Significance of Fablabs in schools

John Dewey described two extremes of education system "Traditional and Progressive Education" in his book "Experience and Education (1938)". According to Dewey, good education should have both a societal purpose and purpose for individual student. Educators are responsible for providing student with experiences that are immediately value and which better enable the students to contribute to society. Dewey criticized traditional education for lacking general understanding of students focusing on content rather than content and process. The other part of education extreme is progressive education, he argued that it is too reactionary and takes a free approach without really knowing how or why freedom can be most useful in education. He emphasized on practical education, which can help the student to prosper and contribute for the society. He emphasized on experience and purposeful learning for the benefits of the society (Dewey, 1938, p-5).

School policies always value a particular activity by building a space for it. If sports are important, schools build a gym and a basketball court. If music education is in demand, school setup a music classroom. Only then can likeminded students gather, do projects, talk about their projects and create a productive environment in schools. On the contrary, there is no space for engineering and innovation for school children. Although, there are medical and robotics labs in schools, but junior students are not allowed to use those facilities. 3D printers would be a tool to make teaching a lot easier by prototyping different models extremely fast with minimum cost. Teachers can use those models for teaching robotics and mathematics to their students (Blikstein, 2013).

In the late 2000s, researchers and educators realized the need of digital fabrication in education. In 2008 Stanford University launched the FabLab@school project and started building FabLabs in K-12 schools around the world. In 2009 the MC2STEM High School in Ohio (USA) opened its first digital fabrication lab. In 2011 the Maker Media launched the MakerSpace project with DARPA funding. In 2011 and 2012 many museums, schools, community centers, and libraries proposed to build digital fabrication laboratories. Digital fabrication and "making" are based on three theoretical and pedagogical pillars: experiential education, constructionism, and critical pedagogy (Blikstein, 2013).

Fablabs would be an ideal platform for elementary students to design and develop tangible artifacts. Students design and develop artefacts with some wooden or plastic sheet, which is not quite exciting, and students lost their focus towards creativity. By using digital fabrication tools like laser cutters and CNC machines, students will engage themselves more actively while holding those tangible artifacts which they create by using digital fabrication tools. Blikstein explained why digital fabrication labs are important in schools. (a) enhancing existing practices and expertise, (b) accelerate invention and design cycles (c) long term projects and deep collaboration (Blikstein, 2013).



## 6. Research Findings

“Additive manufacturing or making is the process of translating a digital design developed on a computer into a physical object”. Digitally making is a platform where an un-skilled person or a school kid can design their own project without having any prior experience in information technology or engineering. Digital fabrication can also be explained as a tool that can be controlled by a computer for producing a physical object which is described in a computer readable file (Berry et al., 2010, p. 168).

It is also known as digital prototyping which is mainly used for 3D printing and prototyping of 3D models. In recent times, digital prototyping became more popular and there has been a massive progress in 3D printing. Architects build fully constructed house with the help of 3D printers. In the field of medical sciences, researchers have designed different body parts, prosthetics and organs of human body with the help of 3D printers. Even 3D shoes and 3D printed cars have been designed through digital fabrication. So, the future of 3D printing and digital fabrication looks quite inspiring. Digital fabrication revolutionized the industrial vision and gave a new hope to the researchers and entrepreneurs. There is now plenty of research carried out to discover modern tools for digital fabrication and to make it eco-friendly technology which can benefit the environment. “Digital fabrication” can be defined as the making of physical digitally enhanced artefacts as well as the making of materialized objects by means of digital models. Following this definition, technologies for digital fabrication comprise of physical computing technologies as well as digital production machines for printing three-dimensional objects and for cutting, shaping or milling material. While digital fabrication in educational contexts has gained popularity during recent years and is often linked to the history of constructionism (Katterfeldt, 2015).

As digital fabrication benefited the industry and researchers believed that digital prototyping and 3D printing will make major difference in future industry, the universities around the globe started teaching 3D prototyping related courses to their students. Dr. Neil Gershenfeld envisioned the idea of FabLab to democratize the digital fabrication technology in the reach of common person, which means that anyone without any technical skills or knowledge can visit FabLab to design and print any kind of his favorite model or artifacts by using digital fabrication technology. FabLab academy was started to promote the idea of democratization of digital fabrication. Through this academy, FabLabs were made in many countries and now this academy is offering multiple courses and workshops to teach digital fabrication. According to December 2017 reports, there are around 1205 FabLab around the world offering digital fabrication technology with modern tools and software (Fablabs.io, 2018).

Looking back at the history when computers were introduced in the market, the prices of computers were skyrocketing so it was out of reach of common people. The computers were only used in big companies or government departments. But later on, the computers became cheaper and people could buy desktop computers for their personal use. The same scenario occurred to mobile phones. Similarly, when the 3D printers were manufactured, they were very expensive that common person could only dream of buying 3D printers for personal use and now 3D printers are also in the reach of personal use. The technology is becoming more accessible to the human beings. The aim of FabLab was to introduce digital fabrication technology to the common person which means it should be part of educational institutions and schools where not only university students can learn the

modern technology, but also junior students of elementary schools can benefit from this technology (Gershenfeld, 2012).

Unfortunately, most of the universities are equipped with 3D printing technology but schools are still lacking behind, and junior students have less exposure to this modern technology. Now, when almost every junior school student has his own smartphone and they can download multiple mobile applications e.g. social networking and gaming applications and use those applications quite frequently. They should also have access to digital fabrication technology, which is not only beneficial for their studies but also helps them to think and innovate modern 3D artifacts. There are some challenges students face during digital fabrication and design thinking process. These challenges occurred due to lack of motivation of students towards group work and design thinking process. The process of digital fabrication starts with design part and to design something innovative and unique, students will turn towards design thinking, which helps them in conceptualizing and understanding the process of designing. It also helps students to work together in pairs to solve problems and negotiate which is very important. Nowadays, usually students spend their time interacting with their smart phones and avoid working in groups which leaves negative impact to their personality and they become socially isolated. By involving the students in the process of design thinking, it would help students to work in groups and become more social (Smith et al., 2016).

Neil Gershenfeld presented the idea of digital fabrication to provide a platform where anyone can gather their thoughts and come up with an idea to build anything from scratch. "The aim is not to build a drone but to build a complete vehicle that can fly right out of the printer". In early 2000s, Neil Gershenfeld with the help of MIT introduced the idea of FabLab, where anyone regardless of their age can participate in fabrication process and design their favorite artifacts through CNC machines and laser cutters. The idea of open innovation concept was very unique and attracted researchers to find more resources to promote this idea. (Gershenfeld, 2012).

With the increasing presence of technology in everyday life, it is important for children to get a sense of the value of technology for issues in our society. For example, modern communication technologies have the potential to decrease social isolation of elderly, or sensing systems can support people in reducing energy usage in the home. To understand such value of technology, children should not only learn the modern technology skills like programming and robotics, but they should also gain insights in how such technologies can impact society. Various developments have already facilitated the introduction of digital tools in the school context to teach children about digital literacy. These include FabLab equipment, such as 3D printers and laser-cutters. There are several digital toolkits for school children for learning purposes which includes LittleBits, LegoWeDo and MakeyMakey. Digital literacy can be defined as the ability use, understand and evaluate technology and also to understand technological principles and strategies required to develop solutions and realize specific goals. (Tilde et al., 2015; NEAP, 2010)

Programming tools such as Scratch and NetLogo have achieved unprecedented popularity and made coding accessible to millions of students. Today, the range of accepted disciplinary knowledge has expanded to include not only programming, but also engineering and design. In addition, there are calls everywhere for educational approaches that foster creativity and inventiveness. Two decades ago only professional computer programmers can do coding and only big companies can afford computers due to their sky-rocking prices but thanks to researchers' hard work and dedication, now a school going kid or a common person can buy their personal computers and learn



programming. They also recognized in their study report the difference between technological literacy and technical competence. It means there should not be any difference between vocational training and professional engineering, but the knowledge should be valuable for every citizen (Blikstein, 2013).

Technological innovation not only brought comfort to human life but also make it easy for students to learn modern technologies quickly. With the help of computers and different hardware tools, now it is easy to make any physical object. 3D printers and similar hardware tools help us to not only design university projects but also help us to design eco-friendly houses and prosthetic parts of human body. The first 3D printing technologies appeared in 1980s and began operational in the early 1990s. at the time, only plastics could be used. The level of details and quality of finish were rather low, which meant that only “rough” looking objects could be printed. Printing was slow, expensive and restricted to small objects. Consequently, the first application of 3D printing technologies was rapid prototyping, i.e., the ability to rapidly build plastic models of objects. In the second half of 1990s, the advent of 3D printers using head-resistant polymers and metal alloys triggered the second stage of adoption of 3D printing, which was rapid tooling. In the last 2000s, the cost of 3D printing began to be low enough with high quality printing to start directly manufacturing final products with 3D printers (Rayna & Striukova, 2016).

## 6.1 Digital Fabrication and children

In the world today, where children are obsessed with their smart phones and latest technology gadgets e.g. play station, and Xbox and these devices are turning our children into lazy and unproductive human beings. These digital natives are smarter than their older generations. So, there is a need to make them realize their potential and make them more productive and innovative. By introducing some innovative technologies like digital fabrication, children can become more creative and innovative instead wasting their time in useless activities.

3D printing/digital fabrication is not only associated with classroom for children. Children not just spend all their time in classrooms. There are all sorts of other activities, and aspects of children’s culture, that might be strongly affected over the next decade by 3D printing. Children use computers both in classroom and out of the classrooms and for all sort of purposes relevant to their own lives and interests. As designers, then, it is worth keeping in mind a broad perspective about how to create novel fabrication tools and projects for children (Eisenberg, 2013).

Eisenberg emphasized a realistic sense of optimism and enthusiasm about the cultural and intellectual potential of children’s fabrication. The designers should concentrate their energies in brining 3D printing, productivity into children’s lives. He intended to spark exploration of fabrication beyond the boundaries of the current marketplace, focusing on the interests, capacities, learning opportunities, and days-today culture of children. He focused his research on five challenges for designers of 3D fabrication system for children which can improve children’s learning and development towards digital fabrication. Those challenges include; expanding the range of physical media available for printing, incorporating ideas derived from “pick and place” mechanisms into 3D printing, exploring methods for creating portable and ubiquitous printing devices, creating tools for hard-customization and finishing of tangible printed objects and, devising software techniques for specifying, altering ang combing 3D elements in the context of printing (Eisenberg, 2013).

## 6.2 Digital Fabrication in schools

Today's world is very different than the world where our parents were living. In 21<sup>st</sup> century, these digital native children are more fluent in digital technologies, video games, smart phones and social media. Nowadays, students are continuously evolving so rapidly that parents and educators would not be able to catch up. According to current situation, teachers need to adopt more radical and innovative methods to engage students in creative activities. For example, students could learn algebra far more quickly and effectively if instructions were available in game format. Students would need to beat the game to pass the course. If educators want to have relevance in this century, it is crucial that we find ways to engage students in classroom. In this century, teachers can no longer decide for students, they must decide with them to get their feedback about the curriculum (Prensky, 2005).

The single most important differentiator between previous and current century digital technology is ability to programming and coding. The 21<sup>st</sup> century kids are already programmers to some extent. Every time when they download a song or video game via Google search or some mobile application, in fact they are programming which shows that they have some sense of programming. To prepare kids for future, teachers must help them maximize their tools by extending their programming and innovative abilities. Many schools are already applying the method which requires the students to submit their assignment through email or giving any assignment like using Flash or Scratch and submit their assignment through their email ID. Some schools are also offering summer camp game programming courses for students, which is a good initiative to engage students during their summer vacations into creative activity to learn something different apart from their studies (Prensky, 2005).

In old times, when teachers were using traditional teaching methods like hardcore learning, attending lectures and memorize the course books. The students got bored in their school workshops and took less interest in their science and engineering labs. Because there were not many resources to attract students towards learning and participating in science workshops, the students were dependent to their teachers and course books. But now time has been changed, students are entering in the world where they must learn to be self-directed, self-motivated and flexible to adapt new technologies. The schools are becoming increasingly unexciting and irrelevant institutions for students. It's only function for many students is to provide them with a credential that their parents say they need. The exciting part of the day for school children begins after school. It is the time when students can enjoy their digital friendly gadgets like mobiles, computers and video games. Now, when almost every commercial and non-commercial institution needs programming gurus and when you ask from those employees, most of them respond that they started their programming carrier as a hobby after school. It is revealing that many students demanded their school technological labs to remain open until midnight. In 21<sup>st</sup> century, the teachers should desperately need to find the ways to integrate students' technology rich after-school lives with their lives in school (Prensky, 2005).

Children do not have the attitude towards the creation process and may not see making as an engaging activity they want to invest in. When students are engaged in class, they learn more. It is important that teachers create the right classroom environment for learning: raising student expectations; developing a bond with students; establishing routines; challenging students to participate and take risks. These all affect how much their students engage and learn. According to (OCED, 2008) report remarked that "technology is everywhere, expect in schools which shows that there is still need to improve technology standards in our school laboratories and engage students in innovative projects by



providing them latest technological tools. The educators need to integrate their course with technical projects to promote critical and design thinking in students. As far as student concerns, the students need to think creatively, plan systematically, analyze critically, communicate clearly, design iteratively and learn continuously to be successful in future (Goss & Sonnemann, 2017).

The schools are applying modern teaching methods to prepare students for future challenges. Project based learning is also part of that method to let students' part of some project where they can think independently and share their ideas with their fellow group members to make their project successful. The probability of success becomes higher through experiment or engaging students in Do-it-yourself projects instead of working alone.

The role of teachers in classrooms is to offer their students opportunities for hands-on exploration by engaging them in creative learning through their projects. According to Papert, "knowledge construction happens especially effectively in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a technological artifact" (Papert, 1980.)

Three different kind of teaching approaches were discussed by Eguchi, (2010), which are usually applied in our schools:

- "Theme-based curriculum approach, where curriculum areas are integrated around a special topic for learning and studied mostly through inquiry and communication.
- Project-based learning approach, where students work in groups to explore real-world problems.
- Goal-oriented approach, where children compete in some challenging tasks in any workshop or tournament. These tournaments are mostly arranged outside of school premises."

These approaches are far better than traditional teaching techniques but there is still room for improvement in these approaches by using our school laboratories as part of classroom. The plight of the situation is highlighted by some researchers. The robotics industry so far mainly aims at humans using pre-programmed and pre-fabricated robots. The ways in which the robots are made and programmed is a "black box" for their users. Unfortunately, the same "black box" method is followed very often within educational robotic applications where the robot has been constructed or programmed in advanced and is introduced in the learning activity as an end or a passive tool (Mitnik et al., 2008).

Fabrication Laboratories which are also famous in students with the name of fabulous laboratories were launched in schools around the globe for the purpose of creative learning and design thinking. Most of these labs are equipped with 3D printers and laser cutters to help students create their real-life objects and artifacts through computer aided design tools. School labs are normally used for medical or engineering purposes where students can experiment some medical or engineering tasks individually or in groups. But Mike Eisenberg presented the idea to use those school labs for fabrication purposes. In 2005, a program "Learn2Tech" from MIT was introduced to build a platform where educators and engineers work together to teach school children about digital fabrication. After the unprecedented success of the program, Stanford University launched another project FabLab@school where researchers and educators conducted workshops for junior and senior school students. A research study was conducted with school children and

analyzed that integrating digital fabrication into formal educational contexts is by no means a straightforward process. They also stated in their report that digital fabrication in primary and secondary education can benefit from design thinking as an integrated part of the educational set up. Design thinking theory must be accordingly appropriated to suit children and teenagers in educational environments, in which motivation and collaboration, direction and vision in the process cannot be presupposed but must be carefully developed (Smith et al., 2015).

In 2004, Paulo Blikstein presented an idea during his research to bring digital fabrication into educational paradigm. He launched “FabLearn” project with the support of Stanford university researchers and designed first-ever digital fabrication laboratory at a School of Education. FabLearn laboratories are expanding their network of digital fabrication in educational institutions around the world. These laboratories organized digital fabrication and other state-of-the-art technologies for the junior and high school students with the help of educational institutions. There is also a FabLearn workshop in University of Helsinki, Finland. Innokas network is part of University of Helsinki and promotes digital fabrication and robotics education in middle and high school students (FabLearn, 2017).

### 6.3 Design thinking as a tool for problem solving

Design thinking is an approach to learning, collaboration and problem solving that focuses on developing students’ creative confidence. Design thinking is a structured framework for identifying challenges, gathering information, generating potential solutions, refining ideas, and testing solution. It can be flexibly implemented, serving equally as a framework for course design or a roadmap for activity.

Design thinking is generally defined as an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback and redesign. Begin successful in today’s modern technological and globally competitive world requires a person to develop and use a different set of skills than were needed before, one of these skills is called design thinking (Razzouk & Shute, 2012).

It can also be described as the confidence that everyone can be part of creating a more desirable future, and a process to take action when faced with difficult challenge. Tim Brown, CEO of IDEO, has redefined design thinking as “a discipline that uses the designer’s sensibility and methods to match people’s needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.” (Brown & Wyatt, 2008.)

Teachers and students engage in hands-on design challenges that focus on development empathy, promoting a bias toward action, encouraging ideation, developing metacognitive awareness and fostering active problem solving. Helping students to think like designers may better prepare them to deal with difficult situations and to solve complex problems in school, in their careers, and in life in general. Schools are usually focusing on increasing students’ proficiency in traditional subjects such as mathematics and reading, via didactic approaches, which leaves many students disengaged. They should move beyond that limited focus and consider educationally valuable skills like design thinking and digital literacy to value, assess, and support. Having good design thinking skills can assist in solving really complex problems as well as adjusting to unexpected changes. If teachers need to prepare their students to be successful in their future life, they should provide them with opportunities to interact with content, think critically, and use it to create more information. (Gee, 2005; Razzouk & Shute, 2012.)



The mandate of schools is to unfold the personality of every student and to build a strong character with a sense of responsibility for democracy and community. This implies developing skills of reflection, interpretation of different information and other complex meta competences. Design thinking can serve as the missing link between theoretical findings in pedagogy science and the actual practical realization in schools. It meets the crucial criteria for effective 21st century learning by facilitating interdisciplinary projects, approaching complex phenomena in a holistic constructivist manner. It thereby leads to a transition from the transfer of knowledge to the development of individual potentials. Furthermore, Design thinking fosters a positive relationship between teacher and students (Scheer et al., 2012).

According to Rachel Smith, “design thinking can help the elementary school students to understand the concept of digital fabrication in more profound manner.” They revealed that the process of combining abstract thinking and concrete doing is far from something that automatically occurs when introducing digital fabrication to upper primary and lower secondary school students. Students between eleven to fifteen years of age did not fully understand the creative and reflective process underlying digital fabrication, and this affects their ability to navigate and perform given tasks (Smith et al., 2015).

The process of creating ideating and reflecting on the process in digital fabrication environments has a close resemblance to design thinking. In the process of digital fabrication and design thinking, the students engaged with ill-defined or wicked problems, and explorations of trial and error, to make their choices based on insight or past experiences. Design thinking offers a well-established vocabulary for addressing the learning processes designers undergo when creating a new digital artifact. Design thinking offers digital fabrication in education an understanding of the fabrication process, by providing students with a vocabulary, a sense of quality as well as reflective and retrospective thinking about their own process and product (Smith et al., 2015).

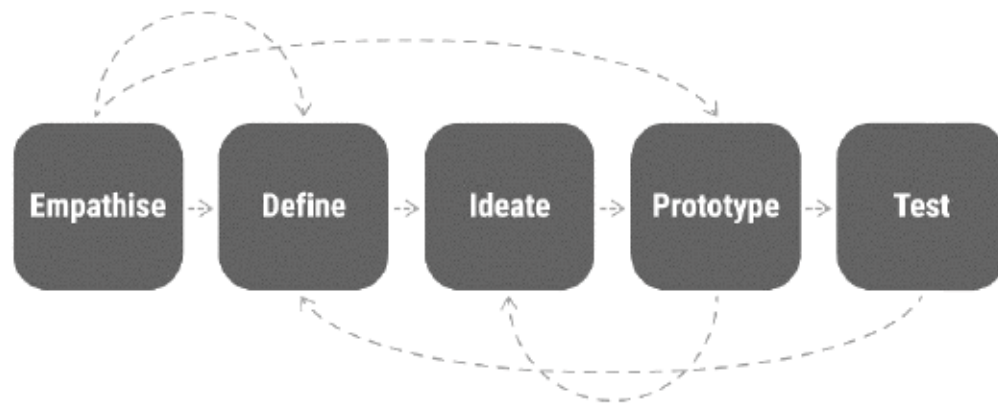
Rachel Smith et al., pointed out five challenges students face during digital fabrication process:

- They find it hard to conceptualize a digital fabrication process.
- They are challenged in navigating the mess process of digital fabrication.
- They lack experience of collaborative creation and negotiation.
- They have limited engagement with diverse materials for digital fabrication.
- They lack an understanding of argumentation surrounding digital fabrication.

Expert designers are solution focused as compared to novices who are problems focused. This appears to be a feature of design thinking that comes with education and experience in designing (Cross, 2004).

## 6.4 Design thinking Process

Design thinking is a design methodology that provides a solution-based approach to solving problems. it is extremely useful in tackling complex problems that are ill-defined or unknown, by understanding the human need involved, by re-framing the problem in human-centric ways, by creating many ideas in brainstorming sessions, and by adopting a hands-on approach in prototyping and testing (Dam & Siang, 2018).



*Figure 1: Design thinking process*

Nobel laureate Herbert Simon introduced the first model of “Design Thinking Process” in 1969. The model consisted of seven stages, each stage had different activities and today’s design thinking process is mostly influenced by his model. There are different opinions by many researchers about number of stages in design thinking process but most popular five stages were proposed by Hasso-Plattner Institute of Design at Stanford Design School; which are mentioned below:

1. **Empathize:** Empathy is the centerpiece of a human-centered design process. The Empathize mode is the work you do to understand people, within the context of your design phase. The first stage of design thinking process is to gain an empathic understanding of the problem to be solved, which involves consulting professionals to find out more about the problem through observing, engaging and empathizing with people to understand their experiences and observations, as well as indulging in the physical environment to have a deeper understanding of the problems. So, empathize can be performed by observations, engagement and listening to the people. Depending on the situations, an extensive amount of information is gathered at this stage to use during the next stage and to develop the best possible understanding of the users and their problems.
2. **Define:** After receiving valuable information from the users, the goal of this stage is to analyze the information and synthesize them in order to define the core problems that have been identified. The define stage can help the designers to gather wonderful ideas to establish features, which allow to solve the problems or let the users resolve issues themselves without any difficulty. The designers synthesize the information through empathy and research and articulate a point-of-view (POV) by combining the three elements; user, need and insight, as an actionable problem statement that will drive the rest of your design work. A useful POV can provide focus and frames of the problems, informs criteria for evaluating competing ideas and empowers the designer team to make decisions independently. By highlighting the appropriate problem is the key to create the right solution.
3. **Ideate:** After defining the problem, the designers move to next stage of gathering ideas and brainstorming to find the ways to solve the problems in best possible means. The designers analyze and synthesize their observations and generate ideas with the help of their team members to identify the possible solutions of the concerned problems. Each team member defines his/her own idea for solving problems, all the ideas are gathered, and best ideas can be picked up to solve the problems. Different techniques can be applied to generate idea; brainstorming, prototyping, mind mapping and sketching etc. In prototyping technique, the designers physically make something with the help of sticky notes or some cardboard which can be helpful to encourage



new ideas. The purpose of this phase is not about coming up with the right idea that it's about generating the broad range of possibilities.

4. *Prototype*: This is an experimental stage which aims to identify the best possible solution for each of the problems identified during the first three stages. The design team produces different types of inexpensive prototype with the help of available resources to find out the best possible solution derived from the previous stage. These prototypes are tested with other designer members or any outsider. A prototype can be anything that a user can interact with, it can be sticky note, a gadget, a role-playing activity or a storyboard. These prototypes can be modified or redefined according to needs of situation. A storyboard or sticky note can give designers some understanding about the solution but by performing a role-playing activity can bring emotions and responses from the users. The prototyping can take much longer as compared to other phases, but the designers should reduce the timeframe, so they can modify the initial version when required. By the end of prototyping stage, the design team can have a better understanding about the constraints inherent within the product and overview of how real users would feel and behave when interacting with the final product.
5. *Test*: The designers and users test the final product using the best solutions identified during the prototyping phase. This is the final stage of design thinking process, which can be iterative process depending on the user requirements and nature of problem. At this stage, the designers get the feedback from the users and get an opportunity to gain empathy from the users. Testing is another opportunity to understand user requirements unlike initial empathy stage, the designers have now clear picture of the problem and its solution. Even during this phase, alterations and refinements are made in order to prevent problem solutions and derive as deep an understanding of the product and its users as possible. The designers can produce more than one prototype, so the users can compare those prototypes and select the best prototype for testing and implementation.

The above-mentioned design thinking process can be applied in the classroom or workshops in same manner for brainstorming, mind mapping and generating ideas. The teachers can present any real-life situation to students and ask them to perform the five-stage process of design thinking. Since design thinking is closely related to digital fabrication, so this process helps students to get the basic understanding of design thinking, then switch to digital fabrication and make innovative artifacts using lasers cutters and CNC machines.



## 7. Research methodology

Every research is being done with the purpose to achieve an objective related to scientific or social events, problems or processes. The research is the key factor behind any invention. To find solution for those particular problems, a researcher main objective is to discover new facts. After verification of those facts, analysis could be made to identify the cause and effects relationship.

For any scientific or social research, it is important to choose the right research methodology of finding their solution through objective and systematic analysis. A research methodology is based on the systematic plan for conducting research. The research can be planned in two ways, Quantitative or Qualitative research. The key difference between qualitative and quantitative research is their flexibility. Qualitative research methods are more flexible as compared to quantitative research (Mack & Woodsong, 2005).

This research is based on qualitative research methodology. The research is carried out in two different phases. The first phase of the research was to find the existing research material (journals, research papers) for analyzing the importance of digital fabrication and its implementation in educational institutions. In the second phase of the research, a qualitative survey was carried out in two elementary schools located in Oulu, Finland. In an observational study, individual interviews with few junior school students were conducted with the purpose to identify the difficulties of digital fabrication process to implement in junior and senior educational institutions. Another interview session was held with both school teachers to get their opinion about digital fabrication and students' interest towards making and design thinking. As both interviews with students and teachers were part of the qualitative survey and the result is based on those interviews. The data collected through survey was being analyzed under the light of interviews with students and teaching staff about the implementation of digital fabrication in Finnish elementary schools.

### 7.1 Qualitative research

The purpose of qualitative research is to get the deep and broad understanding of the topic or problem from an individual perspective. The research is conducted with the aim to get authentic and clear picture of the problem by conducting a qualitative survey by arranging semi-structured interviews with a small group of people relevant to the research. "The survey is a systematic method for gathering information from (a sample of) entities for the purpose of constructing quantitative descriptors of the attributes of the larger population of which the entities are members". The population under study may include the inhabitants of a specific category like teachers, students, customers and players (Groves et al., 2004, p-2).

Robert. K. Yin (2010), described five features of qualitative research:

1. Studying the meaning of people's lives, under real-world conditions;
2. Representing the views and perspectives of the people in a study;
3. Covering the contextual conditions within which people live;
4. Contributing insights into existing or emerging concepts that may help to explain human social behavior;
5. Striving to use multiple sources of evidence rather than relying on a single source.

The research does not observe social interactions or communications between persons in a given population, but only attributes of the individual members involved, e.g. use of mobile in school children and technology interaction of school children. The main objective of any research should be that it should be transparent, well-organized and based on evidence not just imaginary datasets.

Qualitative research is exploratory in nature, helping researchers to understand detailed information about any topic. Based on the information, a hypothesis can be formulated before gathering data which will help to decide whether the hypothesis is valid or not. While qualitative research can provide detailed information about a topic or an issue, the research is usually conducted among a small group of people which means that it is limited to only describing a general perception of problem so qualitative research would only provide a general consensus of specific group of people (Yin, 2010).

## 7.2 Data Collection

There data in qualitative research is gathered through different forms; interviews, case studies, expert opinions, focus groups, open-ended survey questions and observational studies. In this research studies, open-ended survey questions and observational research was used to get the overall picture of the issue. In open-ended questions, a questionnaire would be prepared with the relevance of the topic and the survey organizer ask random questions from the respondent. This approach gives the respondents freedom to express their feeling about the topic, which provides research exploratory data. This data can be used to support the research question. The observational research is often conducted to observe the group of people, customers or students in working environment to get clear picture of the problem in real life while they are interacting with objects. The social interactions, activities and gestures can be determined via observing physical artifacts, graphics, layouts and gathering materials which could be either in digital or printed material. (Yin 2010).

There are certain procedures to conduct qualitative research in order to get valuable data to support research question. First and most important step in qualitative research is to determine the research question which helps you to understand and focus on the research study. After deciding the research question, research finding was conducted to get the understanding about existing research and studies conducted relevant to research question. In order to get valuable data from respondents, the researcher has to decide the ideal sampling size for the research. The data can be collected through interviews or questionnaires (Austin & Sutton, 2014).

The interview could be conducted via a different form that can be divided into either qualitative interviews or structured interviews. In qualitative research, the qualitative interview is probably the primary approach for interviewing, which is quite different from structured mode of interview. The qualitative interviews are notes taken during discussion with respondents while structured interviews are performed by exploitation of survey forms or questionnaires which will include all the questions that will be asked during interview. In this research, the semi-structured interviews were conducted. The questionnaire was designed based on research findings with the help of thesis supervisors (Yin, 2010).

That data should not be large in numbers, but it should be compact and precise depending on the nature of research question. The qualitative methodologies are generally broad, there is possibility that some useful data will be comprehended out of the research. After collecting the data from respondents, the researcher analyzes the data through different



methods, for example; coding, descriptive statistics, narrative analysis, hermeneutic analysis and content analysis. The final step for qualitative research is to validate the finding and concluding the outcomes of research with their pros and cons (Yin, 2010).

In my thesis, qualitative research has been conducted regarding “Implementation of digital fabrication in Finnish schools”. The qualitative research was designed in a way that few schools in Oulu were randomly selected for interview in regard with their technical facilities provided to students. Some schools were equipped with modern technical tools and facilities but some of them were following the traditional school laboratories procedures. There were very few schools in Oulu which were equipped with 3D printers and laser cutters.

Upon randomly selected schools, laboratory supervisor and technical education teachers were contacted to allow interviewing students and get their feedback regarding digital fabrication facilities in schools. The aim was also to interview teachers and lab supervisors about the prospects of digital fabrication labs in schools and its benefits for the students in their learning. Two schools (Oulu International School and Kastelli School) were selected for qualitative survey. Oulu International School (OIS) is equipped with Laser Cutter and other hardware tools but Kastelli School is currently equipped with basic technical tools in their school lab.

The teaching staff of both schools was very cooperative and helpful in conducting the survey and promised to invite other schools to become part of this survey. The teachers agreed to distribute consent forms to their students in which students were asked to get permission from their parents/guardians regarding qualitative survey. Students returned the forms within two weeks of time and interview with teachers and students was conducted next following week. At the time of interview, questionnaires were distributed to students regarding their exposure to digital fabrication laboratories and interest to participate in FabLab activities. The questionnaires were collected by the class teaches after two weeks and returned. The general purpose of distributing questionnaires to the students was to get an overall picture of their interest in digital fabrication and its tools and also to get an idea about how much students are encouraged to participate in FabLab activities. The interview with the teachers was recorded but students were hesitant to record their interview.

### 7.3 Data Analysis

Qualitative data analysis is the range of processes and procedures whereby we move from the qualitative data that have been collected, into some form of explanation, understanding or interpretation of the people and situations we are investigating. Usually, there are two different approaches for analyzing qualitative data; Deductive approach and Inductive approach. The deductive approach to data analysis involves analyzing data based on structure determined by the researcher. In this case, the researcher gathers and analyze the data based on research question. This approach is easy to analyze the data. Whereas, inductive approach is not based on any structured or predetermined research framework. Therefore, it could be time consuming and long-term research because the researcher doesn't have any clear idea or research question in his mind before implementing inductive approach. The data analysis is the most complex phase of any qualitative research. In order to generate findings that transform raw data into new knowledge, a qualitative researcher must engage in active and demanding analytic process throughout all phases of research. The main purpose of qualitative data analysis is to organize and interpret the data, pattern identification. It is also important for the researcher to realize that the analysis should be easy to understand for a general reader, a



confusing or difficult analysis will create problems for readers. Doing qualitative research is about putting oneself in another person's shoes and seeing the world from that person's perspective, the most important part of data analysis and management is to be true and realistic to the participants. (Sally, 2000; Zubin, 2015.)

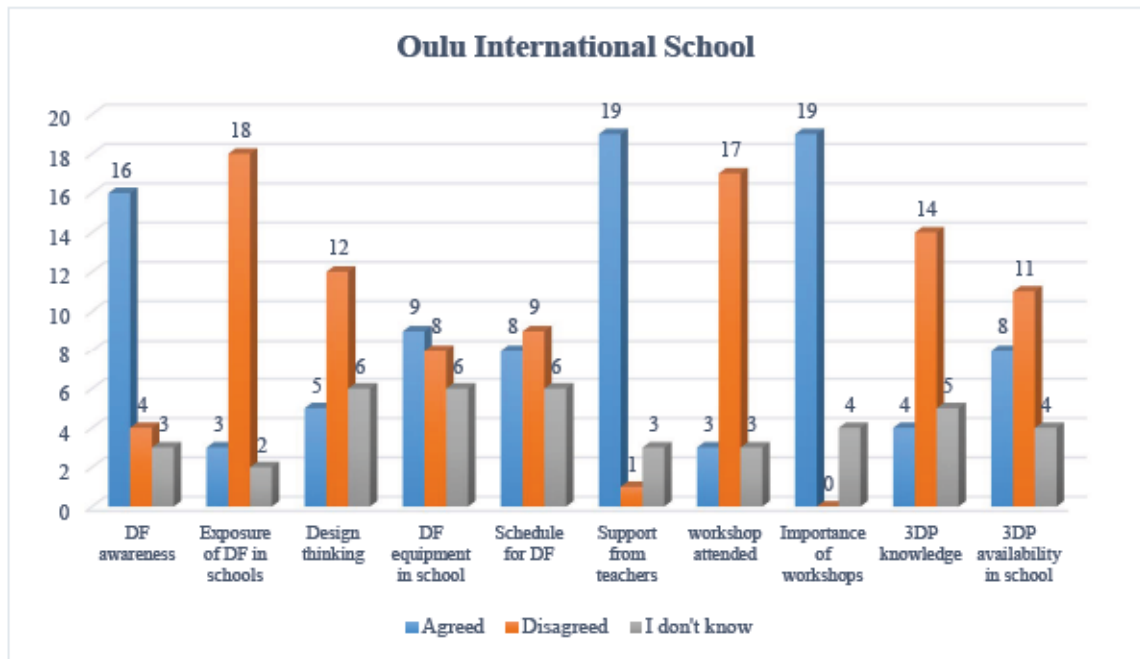
The data analysis that “qualitative data analysis tends to be an ongoing an iterative process, implying the data collection, processing, analysis and reporting are intertwined, and not necessarily a successive process”. When engaging in qualitative data analysis, the researcher not only wishes to highlight the features, but also different steps, procedures and processes that are at the disposal of a researcher. In this regard, the first step in analyzing qualitative data involves organizing the data. It is crucial to bear in mind that the methods of organizing the data, will differ depending on the research strategy and data collection techniques. After organizing the data, the researcher can perform the following stage in data analysis, called description. The process of qualitative data analysis and interpretation can be represented by a spiral image – a data analysis spiral, in which the researcher moves in analytic circles rather than using a fixed linear approach. (Nieuwehhius, 2007; Creswell, 2007.)

## 7.4 Results and analysis

As stated earlier in data collection section, that two elementary schools; Oulu International School and Oulu Kastelli School were selected for qualitative survey. The number of students from Oulu International School who participated in qualitative survey was twenty-three (23) and there were around sixteen (16) students from Oulu Kastelli School, who participated in survey. Questionnaires for students and teachers are attached as appendices (a & c). Given below are the table and bar charts, which represents the students' knowledge and interaction with digital fabrication/3D printing:

### *a. Oulu International School*

Digital Fabrication (DF) awareness	Agreed	Disagreed	I don't know
DF awareness	16	4	3
Exposure of DF in schools	3	18	2
Design thinking	5	12	6
DF equipment in school	9	8	6
Schedule for DF	8	9	6
Support from teachers	19	1	3
workshop attended	3	17	3
Importance of workshops	19	0	4
3DP knowledge	4	14	5
3DP availability in school	8	11	4

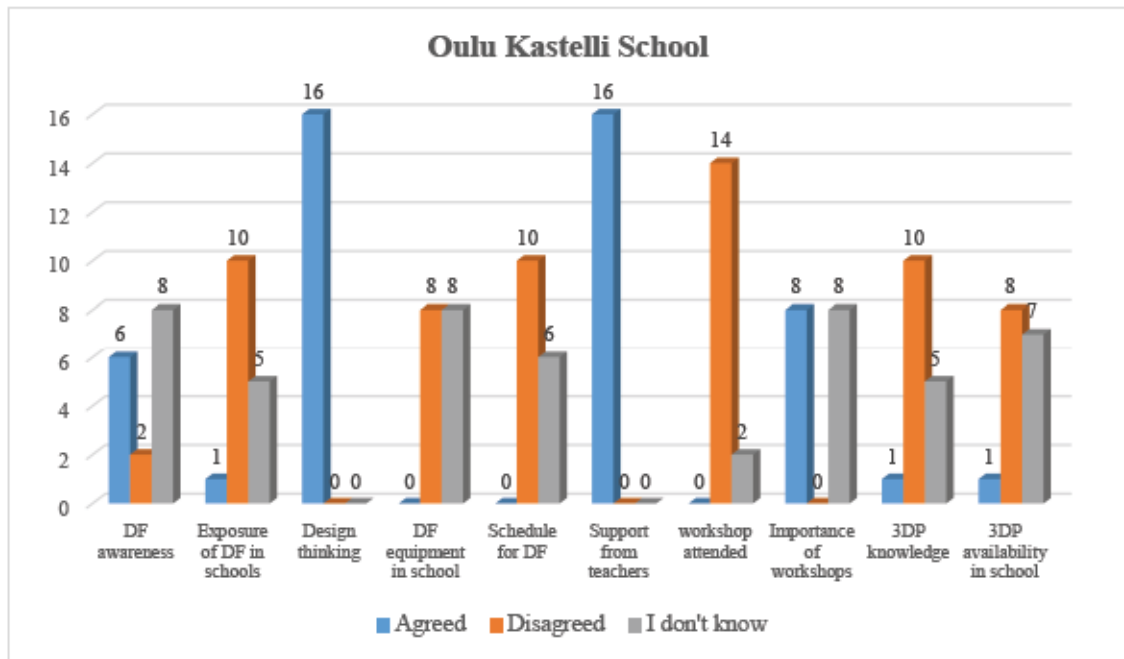


\* DF = Digital fabrication, 3DP = 3D printing

The above chart from Oulu International School illustrates that 16 out of 23 students have basic knowledge about digital fabrication but due to lack of resources and teachings regarding digital fabrication in schools, only few students have exposure to digital fabrication. There are few students who understand the basic concept of design thinking through their teachers. The positive aspect of this survey is that the teachers are willing to support their students to learn digital fabrication and students are also interested to attend such kind of workshops. The school possesses a substantial working laboratory which is equipped with small 3D printer, different kind of tools and cutters.

*b. Oulu Kastelli School*

Digital Fabrication (DF) awareness	Agreed	Disagreed	I don't know
DF awareness	6	2	8
Exposure of DF in schools	1	10	5
Design thinking	16	0	0
DF equipment in school	0	8	8
Schedule for D	0	10	6
Support from teachers	16	0	0
workshop attended	0	14	2
Importance of workshops	8	0	8
3DP knowledge	1	10	5
3DP availability in school	1	8	7



\* DF = Digital fabrication, \*\* 3DP = 3D printing

Oulu Kastelli School survey shows that six (6) out of 16 students have basic knowledge about digital fabrication but due to un-availability of 3D printers in school, students are not aware of digital fabrication. Most of the students participated in the survey, have basic idea of design thinking and the teachers encourages them to learn modern technologies.

Based on research question for the implementation of digital fabrication in schools, two schools from Oulu, Finland were chosen for qualitative survey. Oulu International School and Kastelli School both are based in Oulu, Finland. These schools are conducting classes from 1<sup>st</sup> grade up to 10<sup>th</sup> grade. The focus group of students in this thesis was 5<sup>th</sup> – 6<sup>th</sup> grades, so 5<sup>th</sup> grade students were selected from both schools for qualitative survey. The survey was conducted with the help of class teachers and laboratory supervisor. In this first round of survey, consent forms were given to teachers for distribution to the students. The consent forms were given to the students in respect to get the permission from their guardians regarding interviews and questionnaires reply. Once, the consent forms were received from students, in the second round they were asked to fill the questionnaires honestly and return them to their teachers. Few 5<sup>th</sup> grade students agreed for interview and the interview being done in quite friendly environment in front of their teacher. The teachers were also interviewed to get their opinions about digital fabrication and its benefits for students and the prospects of digital fabrication laboratories in schools.

*Oulu International School (OIS):* OIS is equipped with quite big technical laboratory which have laser cutter and relevant tools for designing artifacts. The laboratory supervisor helped to watch the students' activities in 3D laboratory. The students were very enthusiastic about 3D artifacts and designed different kind of models and artifacts through laser cutter. Most of the artifacts were small house models, fidget spinners, robots, mobile phones etc. Upon interviewing from different students about 3D printing and digital fabrication concepts, mostly students were familiar with the 3D printing, but they did not know much about digital fabrication. Although, there is not much difference between 3D printing and digital fabrication as 3D printing is part of digital fabrication alongwith other categories e.g. additive manufacturing, digital prototyping and digital modeling. When students were asked about the teaching of digital fabrication in their



classroom or laboratories, they told that they already have so many different courses, so it is difficult to spare time for learning other subjects. As digital fabrication relates to design thinking and to design and fabricate modern artifacts, the students need to learn about design thinking. Most of the students were not aware of concept of design thinking.

OIS School has modern science laboratory which also have 3D printing facilities but 5<sup>th</sup> and 6<sup>th</sup> grades students cannot avail the facility. The students use 3D printer and laser cutter after the school time as their hobby but there is no official lesson or workshop for junior grade students. The teachers and laboratory supervisor encourage the students to participate in 3D printing workshops and learn it as their hobby but due to the burden of school studies, students cannot learn this technology as their subject. FabLab is the place where anyone is welcomed to learn about digital fabrication and design their own conceptual artifacts. At the moment, there is only one FabLab in University of Oulu and OIS students never visited that laboratory.

*Kastelli School:* Kastelli School is one of the modern and newly built school and college in Oulu, Finland. It has modern technical laboratory for junior and high school students. The laboratory is equipped with different technical tools and laser printers, but it does not have any 3D printing facility in laboratory premises. Students learn wood and metal cutting technologies in school laboratory but due to non-availability of 3D printer or laser cutters, it is not possible for junior students to learn about digital fabrication.

The teacher of 5<sup>th</sup> grade class helped in conducting qualitative survey. The consent forms were distributed to the students to get the permission from parents for organizing interviews and answering questionnaire. After receiving consent forms, students filled the questionnaire and returned it to the class teacher. Some students also answered the short interview questions in regard with the questionnaire. In the interview, they were asked about the exposure of 3D printing in their classroom or in school. Most of the students replied that there is no such facility in our school and they have never attended any workshop about digital fabrication. Since there is no digital fabrication laboratory in school so they did not have any experience using digital fabrication tools. As already asked from OIS school students about design thinking lessons in classes or workshops, same question was asked from Kastelli school students and their answer was that they have other workshop lessons for designing artifacts through wood and metal cutting tools where they learn how to design and craft various artifacts but they did not have any specific design thinking lessons during their busy class schedule. Few students have once visited FabLab during their summer holidays and designed some key chains and name-tags but they did not have any serious intention to learn digital fabrication.

The class teacher was very eager to introduce modern technologies to his students and encourages his students to participate in learning new technologies. The teacher told about his class participation in robotic competition which was very successful experience and students showed massive interest in robotics and other modern technologies. In continuation of this effort, the teacher organized his class visit to Oulu FabLab where students learned about laser cutting technology and also about the whole process from designing until final product of 3D artifacts. The students designed some interesting badges and key chains and then process those artifacts through laser cutter with the help of FabLab supervisor. The school children were very ambitious and showed their interest to visit FabLab again with their parents and learn more about other digital fabrication technologies. Some images showing activities of school children visiting FabLab, University of Oulu in Finland are given below:

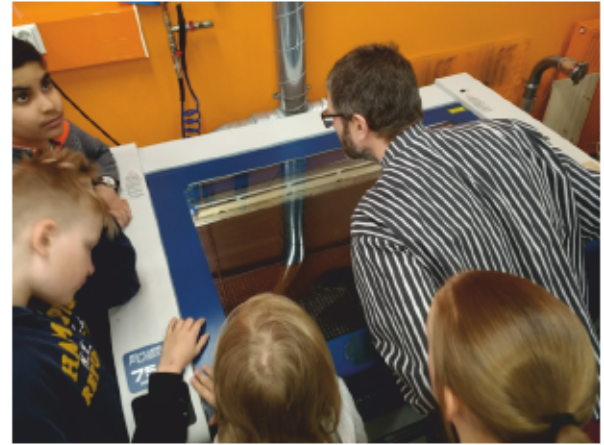
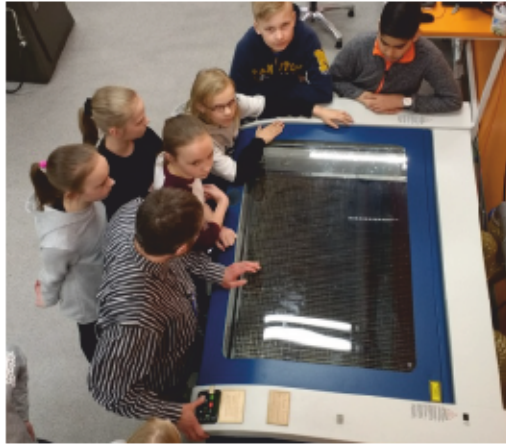


Image 2: 5th grade students of Kastelli School learning laser cutter techniques from lab supervisor in FabLab, University of Oulu, Finland



Image 3: 5th grade students of Kastelli School learning the design process of 3D artifacts in FabLab, University of Oulu, Finland

Image 4: A view of FabLab, University of Oulu, Finland

In this thesis, the results are based on research findings and qualitative survey conducted in Finnish elementary schools in Oulu, Finland. The research findings have been carried out by randomly picked relevant research papers, journals, websites and books available through online search engines and university libraries. Although, there is not much literature available regarding digital fabrication implementation in schools in order to get detailed overview of the research questions. The core theme of the thesis was to find out digital fabrication and its implementation in elementary schools in Finland.

The concept of FabLabs in Finland is not recently introduced. Most of the universities in Finland are teaching digital fabrication since last decade and many universities have their own FabLabs, where they have necessary digital fabrication learning tools. The schools in Finland are still struggling to launch their own FabLabs for learning purposes. However, some schools have small scale 3D printers for technical education purpose but there is lack of proper digital fabrication courses or workshops. The teachers in Finnish K-12 school are quite familiar with digital fabrication, 3D modeling and printing but they cannot arrange any courses for junior students. There are some workshops and project-based learning about digital fabrication for senior or upper grade students. According to the teachers, as K-12 students are not familiar with geometry and advanced mathematics,



so it is difficult for students to learn and design digital artifacts. Some of K-12 students are familiar with digital fabrication and 3D printing but they never used digital fabrication for learning purpose. According to qualitative survey conducted for my thesis with 5-7 grade students, the students are eager to learn digital fabrication and design their own artifacts but due to school hours they cannot spare sufficient time to visit digital fabrication labs in universities. In case, schools have FabLabs which will attract students to come and learn digital fabrication.

## 8. Discussion

The foundation for learning in elementary school students can be laid out by creating physical objects with a purpose, which includes creativity, problem solving, design thinking and basic computer skills. The first step towards STEM oriented future can be taken by using 3D printers in elementary schools. 3D printing for schools' help provide inspiration for students across multimedia disciplines from art to information technology. It sets the path for personalized attention to each student, allowing them to choose their learning niche through open ended design and cooperation with their teachers.

As the thesis title depicts that the research is carried out to understand the use the digital fabrication and how important it is to implement the digital fabrication in school science laboratories. In the following paragraphs, a brief answer will be given to the research questions:

*Research question 1: Why it is important to implement digital fabrication in Finnish elementary schools?*

The purpose of this thesis was to find exposure of digital fabrication in Finnish school. There is very limited literature available for the use of digital fabrication in Finland and it was hard to find out the facts and figures regarding implementation of digital fabrication in Finnish schools. The results and analysis are based on the general overview of digital fabrication use in schools around the world based on research papers and articles. The qualitative survey conducted with two schools in Oulu, Finland. One school (Kastelli School) does not have any facility of digital fabrication or 3D printing and relevant tools but other (Oulu International School) is equipped with laser cutter and open source software for designing 3D models.

The analysis is based on questionnaire and interviews done with 5<sup>th</sup> grade students of both schools. The students in both schools were familiar with 3D printing and few of them have tried designing different models through open source software and laser cutter. There is no lesson or any workshop about digital fabrication in both schools, but teachers and lab supervisors encouraged their students for self-learning about 3D printing and digital fabrication. The students did not have any lesson for design thinking which in my opinion should be mandatory for junior students to promote conceptual thinking and working in pairs which will result into unique ideas and understanding of different concepts.

The students and teachers from both schools were interested to have a digital fabrication laboratory in their schools where students can learn in groups and participate actively to design digitally designed artifacts. The teachers from both schools were also interested to teach about digital fabrication in their class lessons but due to other compulsory study schedule, it was not feasible to include such lessons. The teachers were hopeful that soon there will be lessons about digital fabrication in their school.

It can be a challenging task for students to design an exclusive product for 3D printing. They have to find a problem and then create something using designing software to solve that problem. Creativity was not an issue with students but using software to design their models was more challenging for them. The students have to simplify their design or modify their concepts based on their comfort level with the software. She also highlighted that the process of 3D designing, and printing takes long time from start to final product. The first step of the process is to identify any problem or thinking about any favorite

object for printing which usually takes around one hour for brainstorming. While using the 3D designing software for the product design may take another one to two hours depending on students' designing skills. It is quite challenging to get the final product within given timeframe. But she acknowledged the benefits of 3D printing and also considered that the passion and commitment shown by students during the process was worth to watch (Winsper, 2017).

*Research question 2: How can digital fabrication and design thinking can revolutionize junior school children learning experience?*

Technology has revolutionized the world and there is no end of this process. Information is everywhere and easy to find, so students should know how to be prepared for the overly stimulating, technology-driven world they will face in future. To resolve these issues, creative and design thinking skills are very important. By combining technology with design thinking skills, teachers can prepare much better students for the world of digital innovation. Creativity and design thinking can be encouraged in students by designing lessons with a variety of options for assignment and tasks. This will encourage the students to take initiative to gain knowledge for completing any task. The use of 3D printers for children and explained why 3D printers are becoming popular in children and what can we build next for future generation. According to Eisenberg, 3D printers are now available with relatively low cost but there are striking parallels between advent of the 3D printer and the home computer. One parallel is the interest that sparked by these technologies in children. Printers may get smaller over time which for children is a good thing. A smaller printer could allow them to create small objects relatively fast, such as being able to print something during a museum visit. For different children's projects, there should be some advanced tools which help children to add details to their model projects and their models should look more realistic. These tools would benefit the children as they could bring their already printed models to life and leaving them with a memento of the experience (Eisenberg, 2013).

Children play games, chat with friends, tell stories, study history or math and today this can all be done supported by new technologies. From the internet to multimedia authoring tools, technology is changing the way children live and learn. Because new technologies becoming more critical to children's lives, we need to make sure these technologies support children in ways that make sense for them as young learners, explorers, and avid technology users. The author believes that the role of children in technology design process is very important. The better we understand children as people and users of new technologies, the better we can serve their needs. Children have their own likes, dislikes, curiosities and needs that are not the same as their parents or teachers. (Druin, 2010; Berman, 1977.)

During the 3D printing process, one of the main challenge children face is software which helps them to design their projects and print those projects through 3D printers. The software for designing models is relatively complicated for elementary school students. By creating a software that can allow for printing a complex shape into simple parts that can be assembled later will help the students. It would make the process of making the model easier, as you do not have to use support during its manufacturing (Eisenberg, 2013).

As digital fabrication and additive manufacturing is gaining popularity in universities and school workshops, 3D printed mobile robots are also getting attention of school and university students. 3D printers are very helpful in making these tiny mobile robots, which can be assemble extremely fast and cheaper. 3D printers can make teaching robotics much



easier and teachers can prototype models fast and with low cost. It would be easier to reconfigure the prototype; you can share designs among others, and it motivates students to develop their own platforms. During the research, robots were designed and printed with a total cost of 57 euros and it took only three hours for printing these robots. According to the authors, software available in the market for 3D printing are expensive and designers have to follow certain guidelines set by the manufacturers, they argued that 3D printer software should be open source and user friendly (Gonzalez-Gomes et al., 2012).

Based upon an analysis of a research with children as design partners, the role of children can be divided into four categories in design process: *user*, *tester*, *informant* and *design partner*. In the role of *user*, children contribute to the research and developer process by using technology. It is helpful for researcher to understand the impact of existing technologies on child users. In the role of *tester*, children test prototypes of technology that have not been released to the world by researchers and they can give their direct recommendations concerning their experiences. These testing results can be used to modify the existing technology according to children needs. As a role of *informant*, children play a part in the design process at various stages, based on when researcher believe children can inform the design process. During the role of *design partner*, children are considered to be equal stakeholders in the design of new technologies throughout the process. As design partners, children contribute to the design process in ways that are appropriate for children and the design process (Druin, 2010).

To help the students thinking like designers may better prepare them to deal with difficult situations and to solve complex problems in schools, in their careers and in life in general. Schools continue to focus on increasing students' proficiency in traditional subjects such as math and reading, which leaves many students disengaged. We should move beyond that limited focus and consider educationally valuable skills like design thinking and digital literacy. Design thinking skills can be enhanced in students by incorporating authentic and intriguing tasks into the classroom and providing opportunities to apply design processes. As students work on assigned tasks, evidence is accumulated to evaluate their performance. Such information can help educators monitor the students' performance. The educators should not just focus on preparing students to perform well on standardized exams, but to equip them with powerful skill sets that can help them succeed both within and outside of school. (Gee, 2005; Razzouk et al., 2012.)

Several forms of thinking can be observed in designing. Design starts as a cloudy idea about how the design/product should look like and how it should work. With the passage of time, this idea crystallizes and transforms into a clear and complete image of the product. The second form of thinking involves the sketches and models that bring the cloudy idea to a more concrete form. Sketches and models clarify the characteristics of the product, helping to form a specific line of thought that facilitates the development process and forms the basis for the design thinking process. The third form of design thinking is the "picture-word cycle," which involves putting ideas into words that helps the designer clarify and elaborate on ideas. However, whatever the form of thinking, the design thinker should demonstrate specific characteristics in addition to creativity (Dorner, 1999).

Design thinking is generally defined as an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback and redesign. Being successful in today's highly technological and globally competitive world requires a person to develop and use a different set of skills than were needed before. One of these skills is called design thinking. Design has been widely considered

to be the central or distinguishing activity of engineering. (Razzouk, 2012; Shute & Becker, 2010; Simon, 1996.)

According to the research findings, there are diverse opinions of researchers regarding digital fabrication. Blickstein, who is also considered as one of the pioneers in digital fabrication described digital fabrication is based on three theoretical and pedagogical pillars: experimental education, constructionism and critical pedagogy. The idea behind the experimental education is originally conceived from John Dewey but also to other scholars and innovators. (Blickstein; 2013; Dewey, 1902; Freudenthal, 1973; Förbel & Hailmann, 1901.)

Paulo Freire's ideology for introducing the latent learning potential of students by providing environments in which their passions and interests thrive. Papert encourages technology in schools not a way to improve traditional education but as an emancipatory tool that puts the most power construction materials in the hands of children. This approach embedded with technology provides the students an environment in which students can concretize their ideas and projects with intense personal engagement. In a typical school learning environment, children use technology to build projects and teachers act as facilitators to implement their projects in a real-world environment (Papert, 1987).

Milara et al. (2018), examined "four different human dimensions concerning digital fabrication within the FabLabs context:

1. *Experience and knowledge*: This dimension refer to the set of abilities or skills to perform tasks referred in certain technical domains.
2. *Confidence*: This dimension has a relation with self-esteem. It indicates the assurance of the person while starting an activity on their own.
3. *Motivation*: It refers to having a reason or being eager to perform a particular activity.
4. *Fun*: This dimension refers to the hedonic benefits experienced while performing a particular activity."

The use of digital fabrication in education provides children with a sustained understanding of digital technology and supports their ability to design with digital material. At the same time, it also offers researchers a way of accessing reflections on the postmodern society mediated by digital technology. Researchers emphasized on creative approach to digital fabrication, enabling a hybrid learning environment that combines digital fabrication, design thinking and collaborative ideation and innovation aimed at addressing complex societal challenges. This definition stresses the entire creative process from early ideation, sketching, and mockup creation to the initial presentation of a prototype. In this process, digital fabrication becomes a vehicle and resource for addressing both personal and complex societal issues. (Schellhowe, 2013; Smith et al., 2016.)

The implementation of fabrication technologies and spaces in schools is still in the very early stages, as is the line of research. Soon the "honeymoon" will be over, leaving school teachers and school managers with only a few clues as to how maker spaces and digital fabrication technologies can be introduced into existing school environments. Smith et al. (2016), as a continuation of their early research which was based on student's engagement in digital fabrication activities set up by the teachers in two schools is now focused on



teachers' competences and skills when teaching digital fabrication and design process. Based on their research, they found four impediments which hinders the performance of teachers. These four impediments are contradiction between a curriculum based and highly goal-oriented school settings, experiment-based and highly explorative maker culture. The four impediments represent that different schools have different educational setting and curriculum according to their demographic situation. (Blikstein et al., 2013; Smith et al., 2016.)

The current model of public education evolved during the industrial revolution. The beginning of 3DP and advanced manufacturing provides the opportunity to re-establish the vital interconnection among the historically related subjects. Once learned in the proper and natural, context, the knowledge will be more readily retained. Achieving the necessary contextualization is more difficult than simply purchasing a 3D printer and placing it in the classroom (Bull et al., 2015).

A Laboratory School also known as Lab School was established in 2013 for advanced manufacturing to develop educational practices. It was joint venture by the University of Virginia's Curry School of Education and School of Engineering and Applied Science in collaboration with the Charlottesville City Schools. The purpose of the Lab School is to pilot and validate instructional resources and activities that can be shared with other schools. Establishing a digital manufacturing program in a K-12 school adds additional complexity in areas in which few teachers or administrators have prior knowledge. A well-designed school fabrication laboratory should include a range of digital fabrication technologies, including computer-controlled die cutters, digital milling machines, laser cutters, and other technologies. An effective plan for a school system incorporates an appropriate mix of these tools (Bull et al., 2015).

Regarding the implementation of digital fabrication in schools, Ford & Minshall investigated the application of 3D printing in schools, universities, libraries and special education setting and described six different categories to promote 3D printing in schools: (1) to teach students about 3D printing; (2) to teach educators about 3D printing; (3) as a support technology during teaching; (4) to produce artefacts that aid learning; (5) to create assistive technologies; and (6) to support outreach activities. They further elaborated the use of 3DP in schools and highlighted that 3DP is being used to support STEM education in schools. For example, in science 3DP was used to introduce atomic structure in Grade 10 chemistry classes. Japanese high school students learned about audio frequency through creating 3D printed police whistles. The research shows that how students have developed their skills in creativity, technical drawing, and product design by using 3DP. The inclusion of 3DP in school curriculum is also positive from another pedagogical perspective as it can provide opportunities for different learning styles to be practiced, including experimental learning and failure. Ford and Minshall explained that despite potential benefits, there are many barriers to the integration of new technologies into the education system. Alongwith institutional, cultural, assessment and resource barriers, these includes teacher attitudes and beliefs and their knowledge and skills about modern technologies. According to Bull et al. "the current generation of teachers is not well positioned to take advantage of these capabilities", which means that many educators do not understand engineering, engineering habits of mind or design thinking because this expertise is not currently provided to teachers in their preparation programs. So, they emphasized that the teachers should be prepared in accordance with the modern technologies which will encourage them to promote modern technologies in their classrooms and workshops (Ford & Minshall, 2017).

Another important aspect of their research was the use of 3DP during teaching sessions. According to Ford and Minshall, the use of 3DP during teaching has been reported to improve student understanding, with these benefits arising during a range of subjects and settings. It is evident that students feel more creative and focused by using 3DP for learning purposes. They are not only learning about their subject, but they also get awareness about how to use 3D printers and their software. For elementary school educators to develop the experience and confidence necessary to incorporate 3DP into teaching, more 3DP educational features need to be included in teachers training, as well as an expanded range of workshops to inform serving teachers. Improved access to teaching materials is also necessary alongside improving teaching skills, and a centralized resource for lesson plans and comprehensive curriculum would help support teaching integration (Ford et al., 2017).

During the process of design thinking and digital fabrication in a school FabLabs setup, there are many challenges teachers have to face to engage their students in a new mode of learning. Three main challenges which teachers have been facing during the FabLab workshops (1) the teacher's experiences relating to the complex design process, (2) teachers' challenges relating to managing the digital fabrication technologies and design materials, (3) the teachers' challenges of balancing different modes of teaching. These challenges depicted that teachers' skill and competencies in the field of design thinking and modern technologies should be at average level where they can easily communicate with the students and deliver their message clearly. Due to lack of experience and skills in modern technologies, teachers may lose their authority and control over their students. The main challenge for the teachers is to give the assignment, control the process and motivate the students from beginning to completion. They also argued that there is a huge difference between modern make space educational setup and traditional education system, which is the primary reason in teaching digital fabrication to the elementary school students (Smith et al., 2016).

Elementary school students usually did not get the opportunity to transform their ideas from conceptual form to physical object. The advent of personal fabrication gives students this opportunity for the first time. To excel in the field of digital fabrication, students will need early access to personal fabrication tools and opportunities to practice. As fabrication tools become increasingly accessible, students will be able to learn about engineering design and experience the thrill of seeing their ideas realized in physical form (Bull et al., 2009).

To engage K-12 school children into design thinking process can be a challenging task for teachers. The students daily enter in classroom to learn something new and perform different task instead of sitting and listening to boring lessons as it has been done in traditional classrooms. Today in this digitalized age of information and technology, children got more opportunities in schools to learn modern technologies through different workshops and events organized by the school. These digital native children are more prone to latest inventions in most of the developed countries. However, in developing countries the opportunity of learning novel technologies is lacking due to less resources and funding in education system (Prensky, 2005).

The teachers should realize that the students are living in 21st century where they have smart phones, tablets, modern gaming devices and unlimited access to internet. They remember latest mobile application on their finger-tips which means the students are already familiar with modern technologies but with the right guidance from teachers, they can learn useful digital technologies which will help them to become future innovators (Lay, 2013).



Grammenos, D, suggested the term “Future Designers” in his article which refers to an interactive and participative crash course that aims to introduce to children the concepts and practice of creativity, design, and design thinking. The course focuses multiple learning styles and intelligences, combining various learning approaches and tools, including lecturing (using a variety of media such as images, videos and music), creative question & answer, constructive – personal and collaborative – hands-on activities, play, humor and fun. The idea behind the article was to attract the teachers and junior school students to participate in design thinking and creative activities (Grammenos & Antona, 2018).

## 8.1 Advantages and Disadvantages of qualitative survey

According to Rahman in the research paradigm, two research methods are mainly used by the researchers to carry out their research work, quantitative and qualitative research. There are two types of approaches for both paradigms, interpretivism and positivism. The interpretive researchers believe that the reality is socially constructed by the humans which can be changed and understood subjectively where positivistic researchers have a belief that the social world consists of concrete and unchangeable reality which can be quantified objectively. Similarly, there are differences between researcher for qualitative and quantitative research methods, whether quantitative research is better or qualitative research. Both research methods are widely used in research fields but there are some pros and cons in doing research using one of these methods. (Rahman, 2016; Corbetta, 2003; Kroeze, 2012.)

*Advantages:* Primary advantage of the qualitative research is the detailed and in-depth description of participant’s feelings, opinions and experiences, which interprets the meaning of their actions. Secondly, qualitative research is less expensive than quantitative research, because the researchers don’t have to recruit participants or use extensive methods. Third advantage of qualitative research is that it is more flexible in terms of time and location. The researchers don’t have to interview a large number of people to get the reasonable data for research analysis and it is much faster to get required results. Fourth advantage of qualitative research is that it is an open-ended research methods and ideas can be evaluated through this method. Humans have two very different operating systems. One is subconscious method of operation, which the fast observation that are made when data is present. The other operating system is slow and more methodical, which needs to evaluate all sources of data before deciding. Fifth advantage is that qualitative research can create industry-specific insights. Qualitative research gives brands access to these insights so they can accurately communicate their value propositions (Denzin, 1989).

*Disadvantages:* The quality of data gathered is highly subjective which means that personal nature of data gathering in qualitative research can be a negative component. If one researcher feels that it is important to gather data, but other researcher feels pointless and would not spend time pursuing it. It can also lead to data that is generalized or even inaccurate because of its reliance on researcher ideology. Another disadvantage of qualitative research is that it is dependent on researcher/interview skills, orientation and interpretation. If the interviewer does not possess such interviewing skills and unable to introduce the research purpose expressively which requires to get required data from respondents than the purpose of the research will not be successful. There is another disadvantage that mining data gathered through qualitative research can be time consuming. The data collected through interviews or questionnaires might be large in numbers. To sort out useful data from qualitative research requires a lot of time. Unless there are some standards in place that cannot be overridden, data mining through

substantial number of details can almost be more troublesome than it is worth in some cases. Qualitative research is creative and innovative in finding results but sometimes it is difficult to present those findings in a certain way. Sometimes consumers misunderstand the research findings and leave a negative feedback. At the end, the last disadvantage of qualitative research is that results extracted from collected data cannot be statistically represented. The qualitative research is perspective-based method of research, which means that responses given are not measured. Comparisons can be made which lead toward the duplication which may be required but for most part, quantitative data is required for statistical representation (Rahman, 2016).



## 9. Conclusion

In the light of research findings and qualitative survey, it can be concluded that researchers are working hard to make the idea of digital fabrication successful for providing the school children FabLab facility where they not only learn this new technology but also interact with computer to design and develop some useful interactive physical objects. Another purpose of digital fabrication for children is to promote design thinking during their learning process. Design thinking provides a platform for students to think empathically, conceive new idea by working together with their student groups, implement their design into real physical objects and test those objects iteratively until it gets into final product. As design thinking provides the foundation for creativity and problem solving in school children. School teachers can play important role in teaching their students analytical thinking by working closely with their students.

In this rapidly changing technology world, where most of the children have their own smart phones and they can download and install multiple games and mobile applications into their phones. The obsession of mobile phone use most likely misleading the school children to wrong direction. It will not only affect their mental health but also make them lazy and socially isolated. The teachers and educational institutions should realize that these students are living in 21<sup>st</sup> century where they have internet access around the clock. Instead of using the traditional teaching methods, the teachers should implement modern teaching techniques embedded with the technology. Today children are not like their parents, the parents might not have internet access and advanced technologies, but children have access to most of the modern technologies.

Digital fabrication provides a platform to school children where they can learn, design and tests their own creations with the class groups. It will also engage students to learn innovative technologies and modern software. Dr. Neil Gershenfeld presented the idea of FabLab to make the technology accessible to common people who do not have technical background. According to December 2017 figures, there are almost 1205 FabLabs around the world and more FabLabs are opening. Dr. Paul Blikstein (2013) in his research encouraged the idea of democratization of digital fabrication laboratories which will revolutionize the world.

Finland is famous for its modern and unique education system and Finnish education standard is rated amongst the best education standard in the world. There is no discrimination in schooling system. Every school in Finland provides the same standard of education regardless of race, culture and status. School children equally spend their time in studies and extracurricular activities. The schools organize workshops, summer study camps and educational trips for learning purpose. According to World Economic Forum report (2016), Finland has one the world's best education system. There are some basic factors involved e.g. school children get more time to play which keeps them mentally strong and active, Finnish schools and colleges have standardized tests system and the teachers prefer students' learning not their grades. Another factor is that the schooling is free from kindergarten to university education. The government supports the free education system which encourages students to study and forget about the income resources (World Economic Forum report, 2016).

Finland is also considered the technology hub in Scandinavian countries. It is popular for innovation and versatile technology in technology field. A number of gaming production companies are based in Finland e.g. Supercell, Rovio, Remedy Entertainment and many

more. Each year, more new startup technological companies are kicking-off and supporting the Finnish economy.

Apart from being more innovative and technologically advanced country, Finland is still laying behind in the technology use in school environment. Only few schools have the 3D printing capacity where children can learn digital fabrication but most of the schools are lacking this facility. There are only two FabLabs in Finland which are located in Espoo and Oulu. The University of Oulu FabLab provides free 3D printing and laser cutting services to students and other citizens. Oulu University FabLab also offers different workshops and short courses related to digital fabrication and its principles. It is also dedicated to arranging school visits to digital fabrication laboratory and teach them the whole process from digital designing to printing the final product.

It is recommended since Finland is providing the best education in respect of technology and innovation; every school should provide basic digital fabrication facility to students and arrange random workshops, boot camps where student can learn digital fabrication. Finland is investing the most on education after the social affairs and health. Finnish students were struggling in the field of mathematics and science but due to efforts of teachers and researchers, this graph is slightly progressing. Since digital fabrication helps the students to improve their design thinking abilities, the students can perform better in critical thinking and analysis process. (Statistics Finland, 2017; PISA, 2012.)

## 9.1 Limitations of digital fabrication

In this thesis, I have tried to find out the benefits of digital fabrication and design thinking for junior school students and how can digital fabrication make difference then other traditional studies. Although, digital fabrication has gained huge popularity in industry and universities and researchers are trying hard to promote this technology and democratize it so that it could be accessible to common human being regardless of their knowledge, skills and racial background but there are some limitations and disadvantages of this technology.

The first disadvantage of digital fabrication is that it is hard to scale down the cost of product which means the cost for each product remains same whereas in industry the cost of product reduces for bulk production. The second disadvantage of 3D printing is that it cannot be used for mass production. 3D printers for industrial use are still quite expensive and to obtain mass product, it is difficult to buy so many 3D printers. The third disadvantage of digital fabrication is that 3D printers take longer to get the job done. To get the final product through 3D printer, it requires at least six to seven hours or in some cases the whole day getting the final prototype/model. Another disadvantage of 3D printers and related tools is that it consumes a lot of energy and due to long process of prototyping through 3D printers may cost hug electricity bills.

In the industrial sector, where digital fabrication has some disadvantages, it also has some threat in educational institutions. The purpose of digital fabrication is to engage students in creative and innovative activities e.g. working in pairs and discussing the new ideas to design something innovative and useful, understanding the design thinking process and implementing that process into their digital fabrication laboratory project. But laboratory supervisors and teachers usually complained that instead of designing something useful and creative most of the students spend their time designing playing model e.g. fidget spinners, key chains and badges.



“Digital fabrication had the potential to be ultimate construction kit, a disruptive place in school where students could safely make, build and share their creations”. Digital fabrication is a new chapter in this story. The students used to make and build things with their parents and friends, but that experience was disconnected from their school, since they did not see a link between the intellectual work in the class room and manual labor. He argued that students in digital fabrication labs are assumed to create useful objects, but they rather tried to design some personal objects like key chains, badges and nametags which he considered as a “keychain syndrome”. During a digital fabrication workshop, in the first session he asked children to create their own liking objects and children designed some key chains and nametags and in the final session he was expecting that children will design something better and more technical and they were still interested in making more key chains. In the light of this discussion, it can be seen that indeed there are plenty of benefits of digital fabrication but there are still some disadvantages in respect of industry and learning institutions which can affect the development of digital fabrication (Blikstein, 2013).

During my research and observation with the Kastelli school students, I was really impressed by the enthusiasm and dedication shown by students for learning the 3D designing and printing process during their visit to FabLab, University of Oulu. They were introduced to different kinds of 3D printing related machines and equipment. The lab supervisor was very helpful with the students and briefed them thoroughly about the designing and printing process. Students were mesmerized by the models displayed in the laboratory designed by professionals and university students. The class teacher also accompanied the students and helped them to understand the whole process. Students were so much excited to design and print their own 3D products but due to time constraints, they were divided into groups for brainstorming and thinking about their design. It was difficult to design and print the product individually due to time limitation.

Although it was wonderful experience for the students to visit FabLab and printed some small models but there were some difficulties during the process of designing and printing. The first obstacle was that mostly students wanted to design and print their own products (e.g. a student brought fidget spinner and keen to print, another student wanted to print his name with the key chain). But due to time constraint and handful resources, it was difficult to let them design their own products, so they were divided into groups. Second obstacle was the designing software, it was difficult being fifth grade students for them to learn and design their models within given timeframe. The FabLabs supervisor and their class teacher helped them in designing their products otherwise, it was difficult for students to learn the software and printed out their designed models. The duration of 3D printing process was another major problem for students. A very tiny object of one group of students took almost one hour to print the final product and other students were in queue to set their design for 3D printing.

In the light of above observations, it could be suggested that there is an essential need for open source user-friendly 3D designing software which should be designed for the use of elementary school students. The complex and professional designing software could be one obstacle for elementary school students to learn digital fabrication. The learning process of designing software can be managed by providing more time and facilities to the students within the school premises. 3D printers are now available in customized sizes but the time duration of printing the models is still much longer than other laser printers. The researchers should also work on this aspect to reduce the time duration of printing process.

## 9.2 Future Research

Based on research findings and qualitative survey, the future research would be beneficial to explore children friendly open source software which would be helpful for children to use the software tools and design their projects and artefacts more effectively. 3D printers available in the school laboratories are relatively slower as compared to professional 3D printers which may affect the performance of children, another goal of the future research will be to look for faster 3D printers for elementary school Fablabs.

Only two schools participated in the qualitative survey, which might not reflect the whole picture of overall use of 3D printers in Finnish elementary schools. In future, it is suggested to widen the range of elementary schools in the qualitative survey to get the results on large scale. During the survey, it is noticed that students are eager to learn digital fabrication and to participate in digital fabrication workshops. Teachers are also supportive and encourage students to practice digital fabrication and design their own artefacts by using 3D printers and FabLabs tools.



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## Appendices

### **a. Questions for Interview with teaching staff**

1. Would you please introduce yourself?
2. How long you have been affiliated with this school?
3. Do you have any experience in computers or programming?
4. Are you teaching any IT related courses to students?
5. How much influence students have with innovative learning?
6. How much technology you use in classroom?
7. Is there any IT lab in school and how much time students spend in lab?
8. How much you are familiar with fab labs (3D printing)?
9. As a junior grade teacher, how do you involve students in IT related activities?
10. If you are familiar with fab labs, then what you think about implementation of fab labs in Finnish schools?
11. If your school have no fab labs, would you like to have fab lab in your school and how much support you will get from management/principal?
12. Is there any course for young student related to interaction design or 3D modeling?
13. Do you think fab labs will motivate students towards innovative and design thinking?
14. What you think that fab lab will a burden for student academic career or will it be helpful for students in future adventures.
15. As a teacher, how do you perceive that digital fabrication will revolutionize the world?

At the end, I will give you a consent form (to be filled by parents) and questionnaire to get valuable feedback from students.

Thank you for your time!!!

b. Consent Form (In Finnish language)

## HYVÄT OPPILAJEN HUOLTAJAT

Koulun niemi koulun oppilaat osallistuvat Oulun yliopiston FabLab –aiheiseen tutkimukseen. Aiheesta tehdään gradu ja aineisto säilytetään jatkotutkimuksia varten.

### Tietoa FabLab -tutkimuksesta

Oulun yliopiston Tieto- ja sähkötekniikan tiedekunnan INTERACT-tutkimusyksikössä on jo usean vuoden ajan tehty monitieteistä tutkimusta lasten ja nuorten osallistamiseksi tieto- ja viestintäteknologian kehittämiseen. Tiedekunnan FabLab (fabrication laboratory) on kaikille avoin digitaalisen pienvalmistuksen tila, jossa on mahdollista suunnitella, toteuttaa ja testata omia tuotteita ja laitteita alusta asti itse. Materiaalina voi olla muovia, metallia jne. ja digitaalisuutta voidaan tuoda esim. avoimen lähdekoodin ohjelmistoilla. INTERACT-tutkimusyksikkö tutkii lapsia FabLab -tilojen käyttäjinä eli digitaalisten tuotteiden suunnittelijoina, toteuttajina ja testajina. Digital fabrication -osaamista, eli sitä mitä FabLabissa tehdään, pidetään yhtenä tarpeellisena tulevaisuuden taitona kansainvälisesti. Osana tätä tutkimusta toteutetaan yhteistyössä Koulun niemi koulun kanssa tutkimus, jossa selvitetään peruskoulujen digitaalisen pienvalmistuksen välineistöä ja sen käyttöä opetuksessa. Tutkimus on lapsellenne hyvä mahdollisuus päästä tutustumaan siihen, mitä digitaalinen pienvalmistus ja FabLab oikein ovat.

### Lupa

Ritaharjun koulun oppilaiden FabLab – aiheinen tutkimus tullaan toteuttamaan syksyllä 2017. Pyydämme teiltä lapsenne huoltajana lupaa siihen, että lapsenne tuottamaa materiaalia voidaan käyttää tutkimustarkoituksessa. Pyydämme teitä myös keskustelemaan lapsenne kanssa, haluaako hän itse osallistua tutkimukseen. Tässä tarkoituksessa pyydämme teitä täyttämään alla olevan kaavakkeen ja palauttamaan sen oppilaan mukana luokanopettajalle/ryhmäohjaajalle viimeistään mannanti xx.xx.xxxx. Voitte milloin tahansa peruuttaa antamanne suostumuksen ilmoittamalla peruutuksesta tutkimuksen toteuttajalle.

### Kiittäen,

INTERACT tutkimusyksikkö/Tieto- ja sähkötekniikan tiedekunta, Oulun yliopisto:  
professori Netta Iivari (netta.iivari@oulu.fi) ja professori Marianne Kinnula  
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Työn tutkija: Muhammad Faheem Khan, opiskelija

Lisätietoja kääntöpuolella



Rastita ja palauta opettajalle viimeistään mannanti xx.xx.xxx.

Lapsemme \_\_\_\_ haluaa \_\_\_\_ ei halua

Lapsemme \_\_\_\_ saa \_\_\_\_ ei saa

osallistua Fab Lab -aiheiseen tutkimukseen.

Oppilaan nimi: \_\_\_\_\_

Oppilaan allekirjoitus: \_\_\_\_\_

Huoltajan allekirjoitus ja nimen selvennys: \_\_\_\_\_

#### Tutkimusaineiston käyttö, suojaaminen ja säilytys

Tutkimuksessa syntyy monenlaista tutkimusmateriaalia kyselytutkimuksen ja haastattelututkimuksen aikana (kyselylomakkeita, ääni- ja videotallenteita). Tutkimuksen aikana kerätty aineistoon luottamuksellista Oulun yliopiston INTERACT-tutkimusyksikkö vastaa tässä tutkimuksessa syntyvän empiirisen tutkimusaineiston säilytyksestä, käytöstä ja suojaamisesta. Tutkimusaineistoa tullaan hyödyntämään yksinomaan tieteellisessä tutkimuksessa (mukaan lukien opinnäytetyöt) ja opetuksessa, eikä sitä käytetä kaupallisiin tarkoituksiin. Julkaisuissa ja tieteellisissä esitelmissä aineistoa käsitellään osallistujien yksityisyyttä kunnioittaen siten, ettei tutkimukseen osallistujien nimiä, eikä muitakaan henkilötietoja paljasteta. Tutkimusaineisto voidaan myös arkistoida sellaisenaan pitempiaikaiseen käyttöön tutkimus- ja opetustyötä varten. Tällöin tieto arkistoidaan tutkimusryhmän toimesta sen käytössä olevilla tavanomaisilla tallennusmenetelmillä ja -tekniikoilla.

Tutkimuksesta on vastuussa professori Netta Iivari (netta.iivari@oulu.fi)/Oulun yliopiston tieto- ja sähkötekniikan tiedekunnan INTERACT-tutkimusyksikkö.

## c. Questionnaire for students:

**Ohjeet:** Varmista, että olette vahvasti samaa mieltä, samaa mieltä, eri mieltä tai voimakkaasti eri mieltä ennen kuin vastaat kysymyksiin

Meidän koulussa	Täysin samaa mieltä	Samaa mieltä	Eri mieltä	Täysin eri mieltä	En tiedä
Olen tietoinen digitaalisesta valmistuksesta (tekemällä fyysisiä esineitä tietokoneiden ja laserleikkureiden avulla) ja 3D-tulostuksella	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Minulla on ollut oppitunteja digitaalisen valmistuksen ja oppinut käyttöä erilaisten Fab Lab työkalut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
jos samaa mieltä, selittää					
Minulla on ollut oppitunteja muotoiluajattelusta (innovaatio, luovuus ja oppimisen kautta tekeminen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
jos samaa mieltä, selittää					
Olemme modernisti varustettu (esim. 3D-tulostimet ja laserleikkaimiin) työpajat / labs. Meillä on riittävästi laitteita digitaaliseen valmistuksen koulullamme	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ilmoittakaa käyttämänne työpajat / laboratoriot ja laitteet					
Meillä on riittävästi aikaa työskennellä näissä työpajoissa	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Meidän ohjaaja rohkaisee opiskelijoita suunnitteluajatteluun (innovaatio, luovuus, oppiminen tekemällä)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Olen osallistunut kesäkouluun / työpajaan digitaalinen valmistus / Fablabs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>